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EMU BATTERY/SMM POWER TOOL CHARACTERIZATION STUDY

Charles Palandati

JANUARY 12, 1982

National Aeronautics and
Space Administration

Goddard Space Flight Center
Greenbelt, Maryland 20771

TM 84975

**EMU BATTERY/SMM POWER
TOOL CHARACTERIZATION STUDY**

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**EMU BATTERY/SMM POWER
TOOL CHARACTERIZATION STUDY**

ABSTRACT

The power tool which will be used to replace the attitude control system in the SMM space-craft is being modified to operate from a self contained battery. The extravehicular mobility unit (EMU) battery was tested for the power tool application.

The results obtained during this study show the EMU battery is capable of operating the power tool within the pulse current range of 2.0 to 15.0 amperes and battery temperature range of -10 to 40 degrees Celsius.

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ACKNOWLEDGEMENTS

The author acknowledges the support of Mr. David Sullivan, Space Power Applications Branch, Goddard Space Flight Center who developed the software programs used in this study.

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All measurement values are expressed in the International System of Units (SI) in accordance with NASA Policy Directive 2220.4, paragraph 4.

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EMU BATTERY/SMM POWER TOOL CHARACTERIZATION STUDY

INTRODUCTION

The Solar Maximum Mission (SMM) spacecraft was launched February 14, 1980. The attitude control system (ACS) has developed problems which have effected the normal spacecraft operation. During the shuttle mission (STS 13) scheduled April, 1984 the ACS will be replaced while the spacecraft is attached to the "flight support system" located in the cargo bay of the shuttle.

A power tool (Figure 1) has been designed and developed to operate from the alternating current (AC) power bus in the shuttle and there-fore the area in which the tool can operate is limited. A direct current (DC) motor is being designed to operate from a battery contained in the tool, thereby allowing the power tool to operate independent of the shuttle's power bus.

Figure 2 shows the Extravehicular Mobility Unit (EMU) battery which is used by the astronauts during EVA maneuvers. The size, weight (4.35 Kg) and nominal capacity (25 Ah) of this silver-zinc battery is compatable with the power tool application. The battery is presently required to support one 15 amp pulse for 5 seconds and seven hours of continuous operation at 3.5 amperes (Reference 1) at the minimum battery temperature of 4.4 degrees Celsius (Reference 2); whereas the gearmotor of the power tool will introduce numerous high pulse current loads to the battery during iniation of removing the bolts from the ACS, which requires a high torque capability from the power tool.

There was no data available to define the EMU batteries' minimum operating temperature required to support the high current for the power tool application in the thermal environment of outer-space, and therefore it was necessary to perform this characterization study of the EMU battery.

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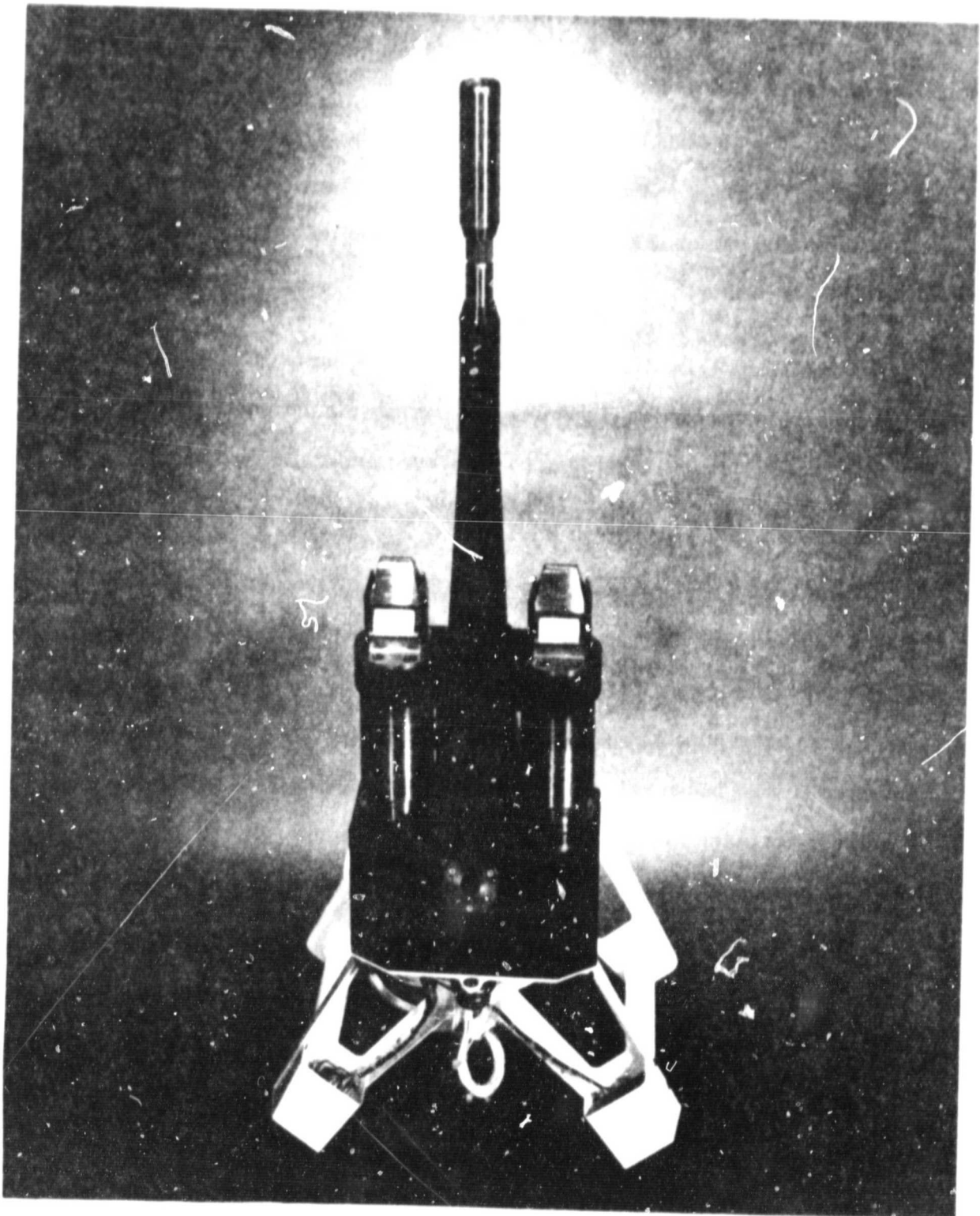


Figure 1. Power Tool.

TEST SYSTEM

The battery was placed in a temperature chamber which controlled the ambient temperature and the remaining equipment was located in the test console (Figure 3). A Hewlett Packard (HP85) microcomputer was used to control the peripheral equipment shown in Figure 4. The discharge current of the power supply was controlled with the resistance card located in the Multiprogrammer and the undervoltage/overvoltage safety limits for preventing cell reversal and overcharging were controlled thru the relay card which was capable of interrupting the AC power to the battery cycler.

The elapse time of each charge and discharge was monitored with the digital clock. The scanner and digital voltmeter monitored the battery current, voltage, temperature and ambient temperature of the chamber. The data recorded during each scan was displayed on the computer's CRT and stored on the charge/discharge discs in the "flexible disc" unit. The printer was capable of recording the "real time" test data and could be turned on or off from the computers keyboard. The printer only recorded several data scans each half hour of discharge (192 data scans per hour maximum) and recorded all the data during charge (6 scans per hour).

The computer required two software programs (charge and discharge) in order to control the test, display and store the data. An additional software program was written to provide a "data lister" which computed the voltage and current measurements to determine the total capacity and power thru-out each charge or discharge. This software program also contains a "plotter program" which plots the entire data or a portion of the data for a specified time period for each charge or discharge.

An ampere hour integrator was used to measure "real time" battery capacity since the data lister could only be obtained at the end of each charge or discharge.

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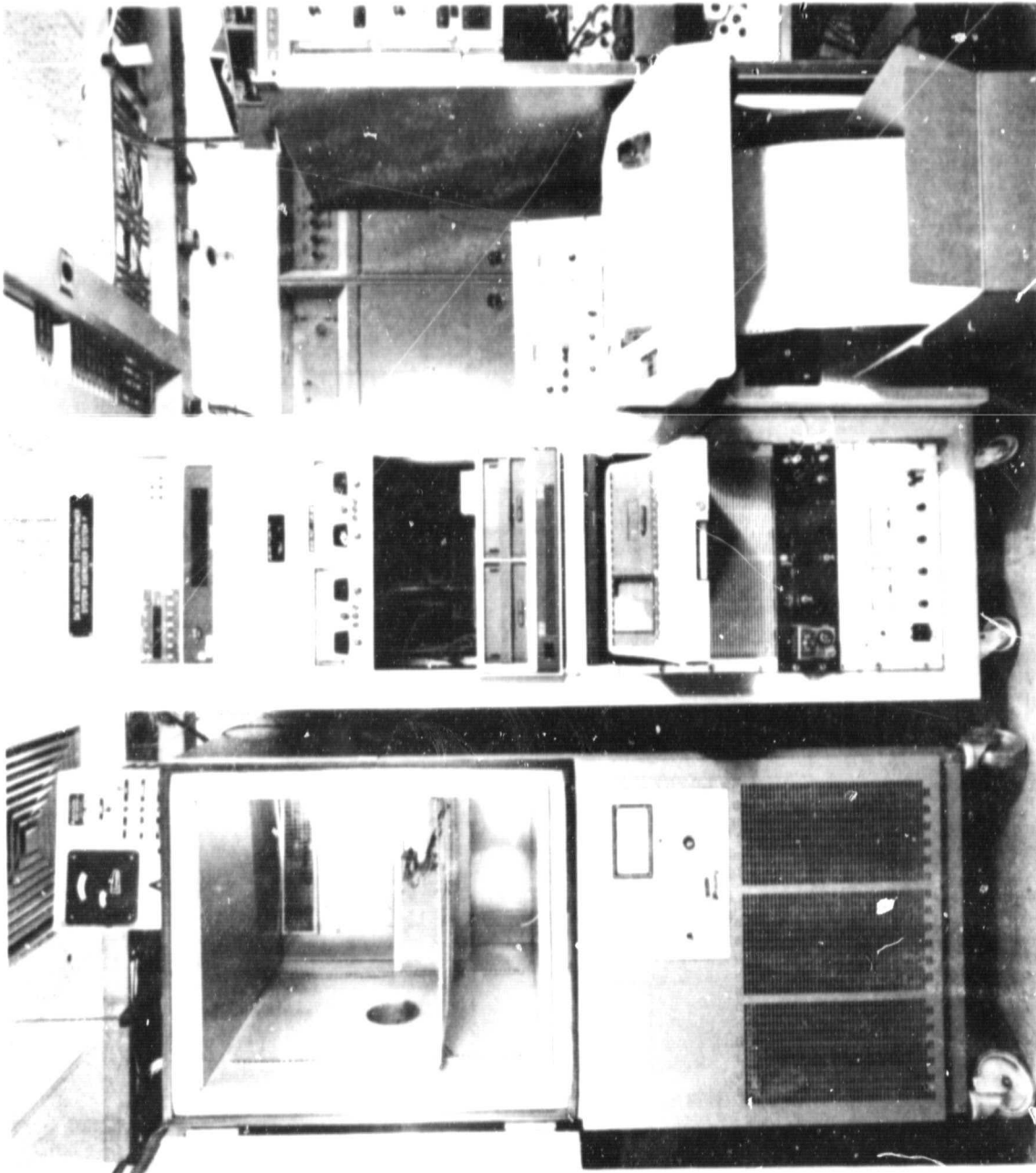


Figure 3. EMU Test System.

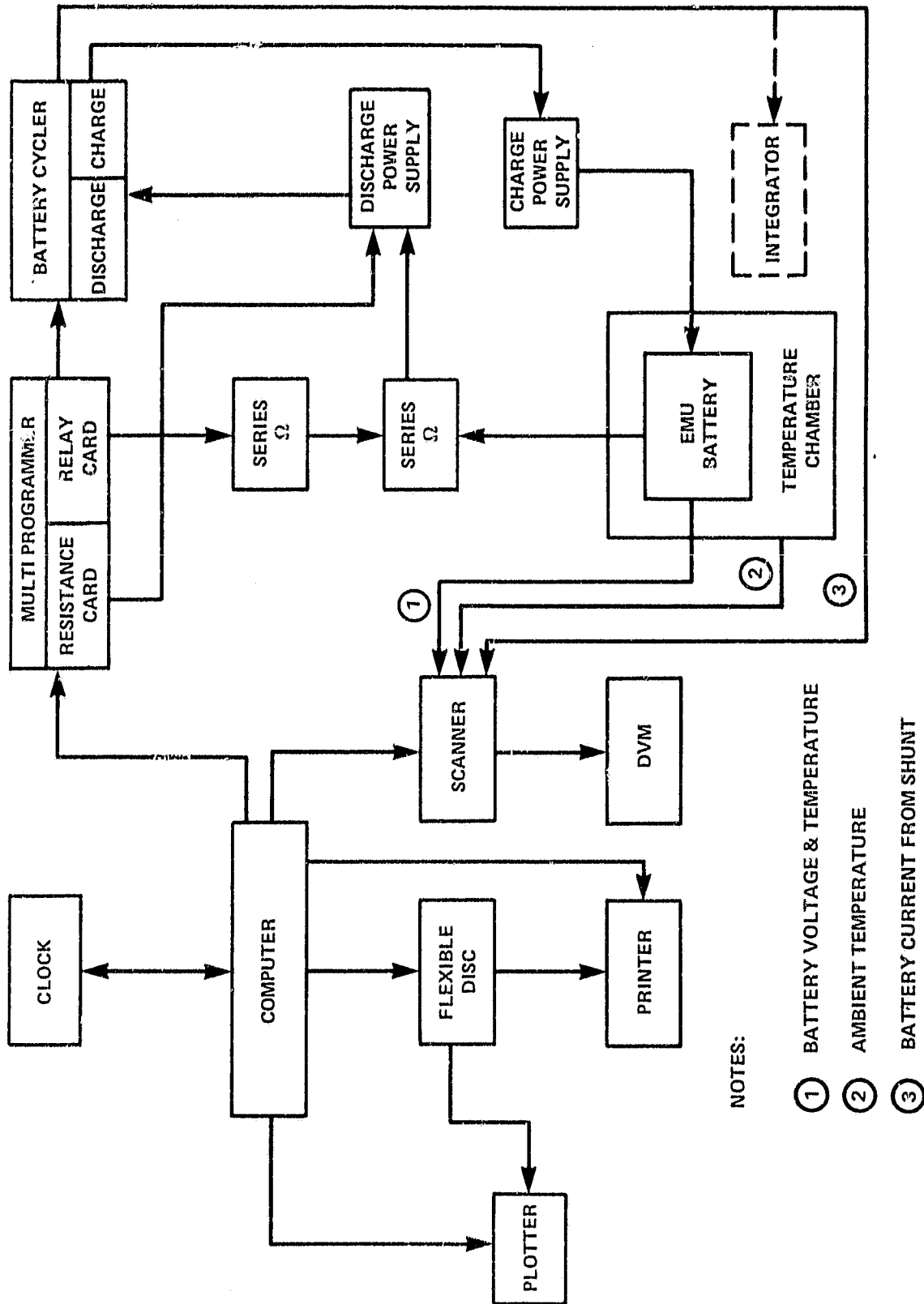


Figure 4. Functional Diagram of EMU Test Configuration.

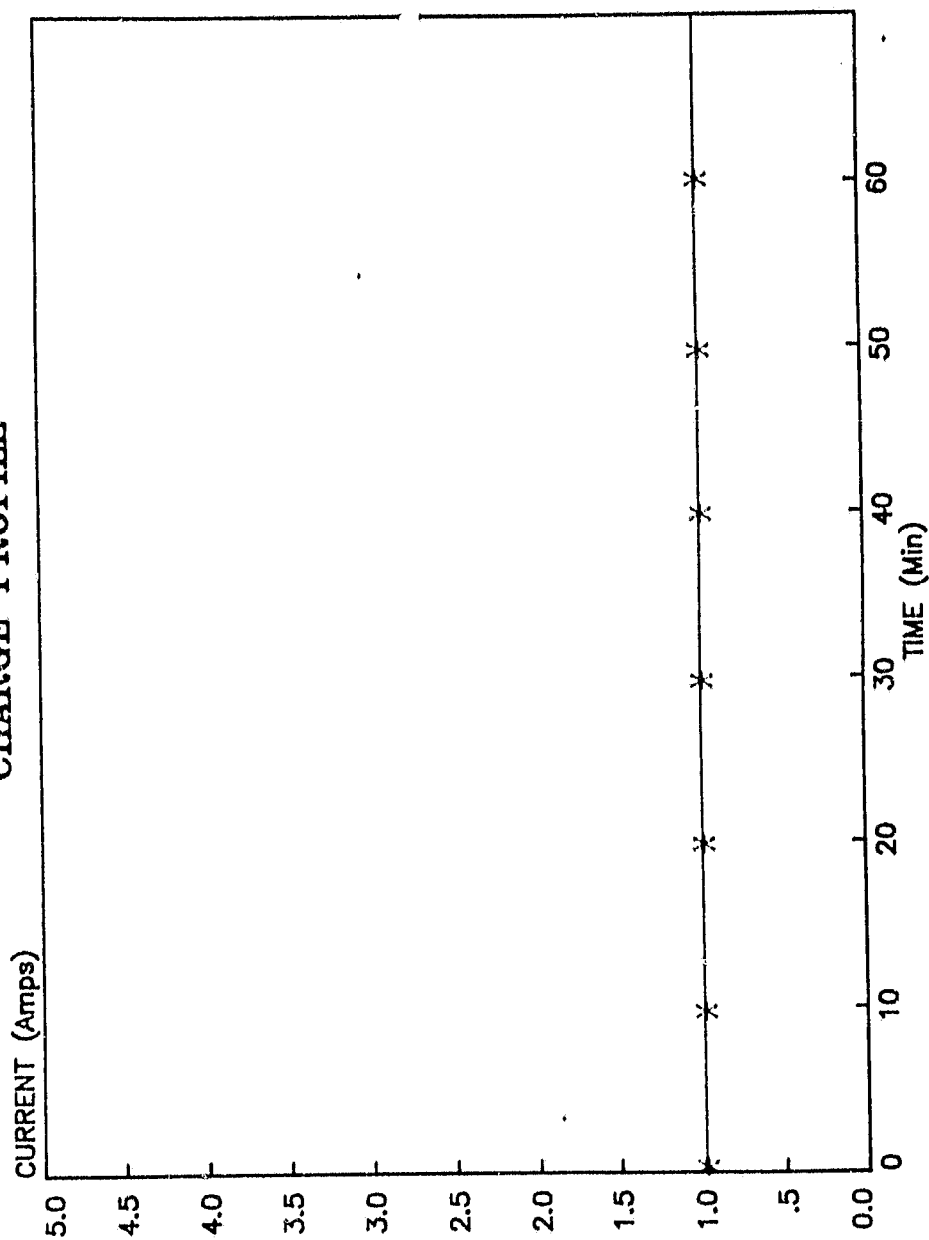
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TEST PHILOSOPHY

In order to determine the temperature range in which the battery could operate for the power tool application, it was necessary to establish discharge voltage profiles at various pulse current loads and temperature levels to a 100 percent depth of discharge (DOD). The 3.5 ampere constant current drain for the EMU regime was used to simulate the power tool "full speed" current drain and the battery's maximum pulse current capability of 15 amperes for a 5 second duration was used to simulate the gear motors "stall time" current load. Figure 5 is a plot of the typical discharge profile used thru-out this study. The battery was discharged at 3.5 amperes and pulsed at 15 amperes every other minute. At minute 59 of each hour the battery was sequentially pulsed at seven different current levels (2.0 to 14.0 amperes). Battery current, voltage and temperature data was monitored every minute, three times during each pulse current level, and one second after the completion of each pulse regime. In order to prevent cell reversal, each discharge was terminated (voltage cutout) when the voltage decreased to 12.0 volts.

Although the power tool application will not require "battery recharging" during the shuttle mission, this battery was recharged many times during the study. Battery charging was performed according to the EMU specifications (Reference 1), 1.5 amperes and 21.8 volt cutout at 20°C or at 1.0 amperes. Two different charge currents were used to allow sufficient time for the battery temperature to stabilize at the next successive discharge regime (approximately one hour per Δt of 10°C). The data was monitored every ten minutes as shown in Figure 6.

EMU BATTERY / SMM POWER TOOL
CHARACTERIZATION TEST
CHARGE PROFILE



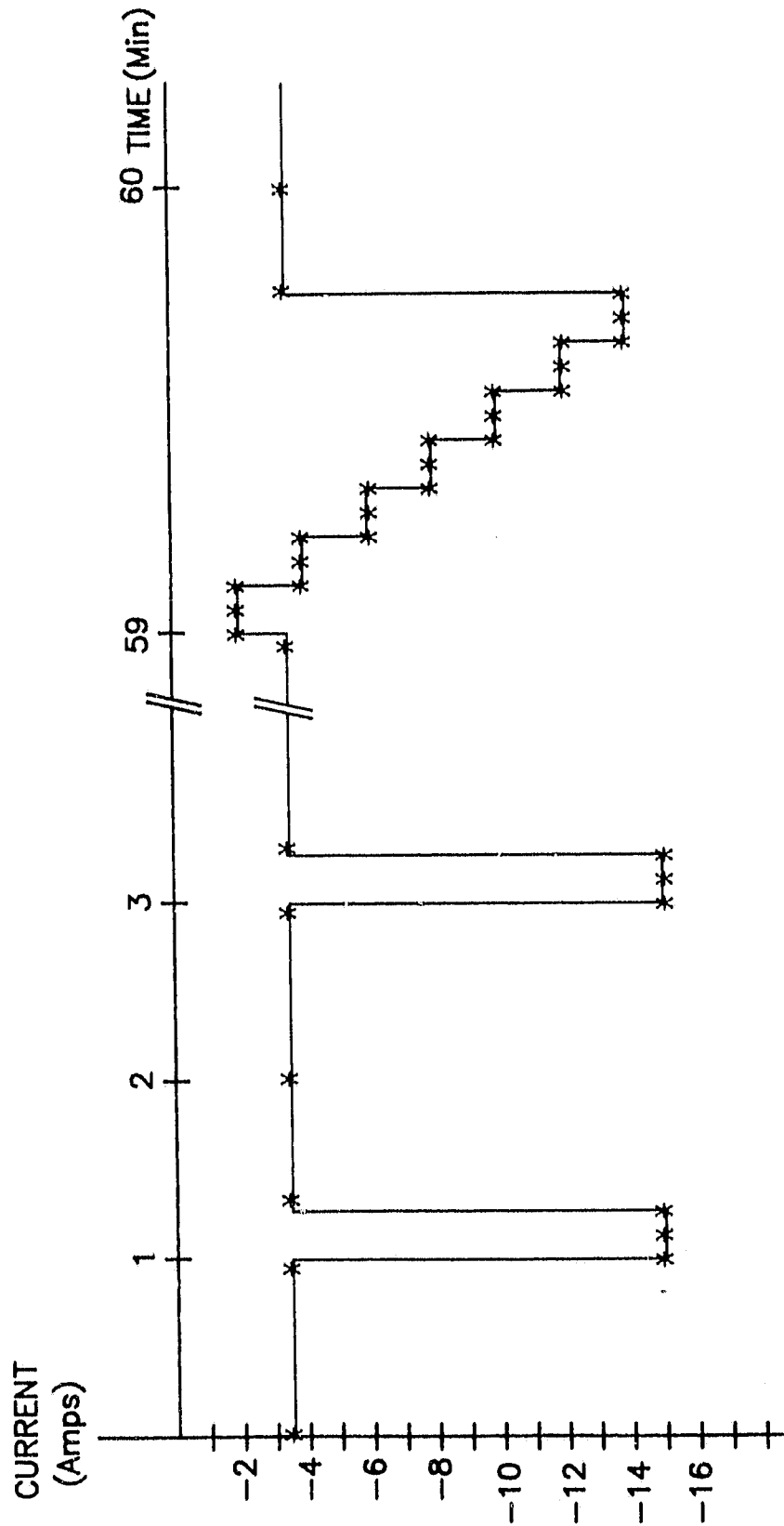
NOTE: * indicates readings taken at this point
Readings may also be taken manually

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Figure 5. Charge Profile.

EMU BATTERY / SMM POWER TOOL CHARACTERIZATION TEST

DISCHARGE PROFILE



NOTE: * indicates readings taken at this point

Figure 6. Discharge Profile.

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EMU CHARGE CHARACTERIZATION TESTS

This battery was the spare battery used for the March, 1982 STS mission. The battery was activated February 1982, charged/discharged three times and received the "pre-shipping" recharge March 2, 1982. The battery was then stored in the "charge" mode for seven months prior to this study. The cell's pressure relief valves which had been secured prior to flight were loosened and a hole was drilled above the terminal post of the sixth cell in the eleven cell battery. Battery temperature was monitored at this terminal post, located 1.9 centimeters below the top surface of the battery.

The battery received a "topping" charge (cycle 1), since the battery had been standing in a charged state for more than 49 days (Reference 2). The voltage cutout (21.8 volts) was disabled since the voltage of a charged AgZn battery initially rises above the cutout voltage and gradually decreases during a topping charge. The magnitude of the voltage where stabilization occurs is governed by the state of charge. The power supply voltage was limited to 22.5 volts in order to reduce Oxygen evolution from the battery cells. The current from the power supply was limited at the beginning of the charge because the battery voltage immediately increased to the power supply voltage clamp. Figure 7 indicates a minimal loss of battery capacity during the seven month stand since the battery voltage stabilized at the 21.8 volt cutout. The battery only received 0.21 ah during the fourteen minute topping charge.

Figure 8 shows the second cycle recharge at 1.5 amperes. The recharge capability of the battery appears to have been adversely effected by the 7 month charge stand. The voltage cutout occurred at only 20.35 ah where-as the capacity output from the battery during the previous discharge at 20°C was greater than 31 ah. Recharge capacity increased significantly during the following charge regimes, there-fore the low charge capacity during the second cycle cannot be attributed to a physical degradation of the Zinc (Zn) electrodes which does occur early in the cycle life of primary type AgZn cells. This battery design is capable of delivering the nominal rated capacity (25 ah) at room temperature thru-out ten charge/discharge cycles (Reference 1).

EMU BATTERY / SMM POWER TOOL CHARACTERIZATION TEST

CONSTANT CURRENT CHARGE - 1.00 Amps . 21.8 V Cutoff . 20 C
 CYCLE # 1 DATE OCTOBER 6, 1982 BATTERY SN 1857

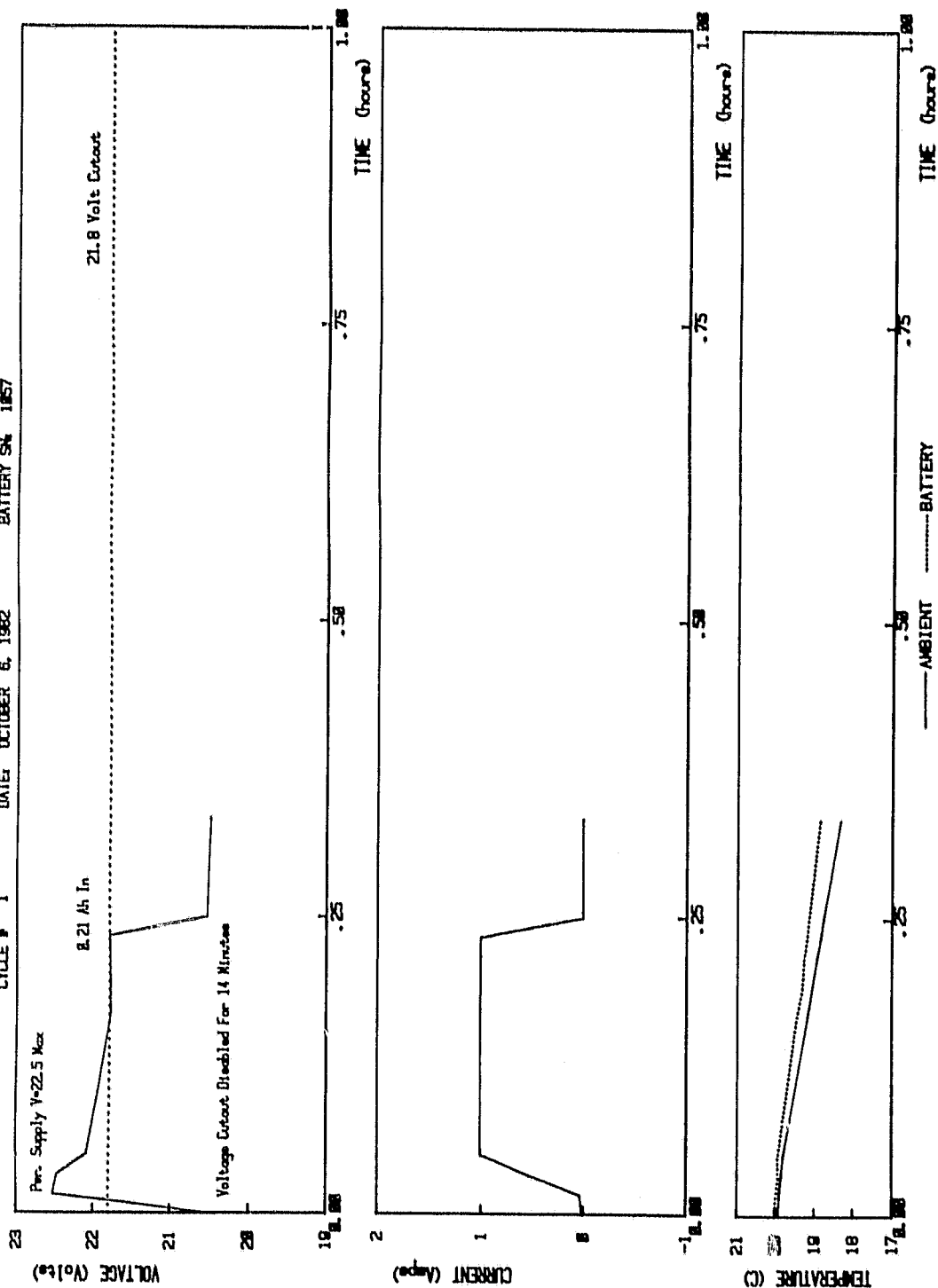


Figure 7. Topping Charge.

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EMU BATTERY / SMM POWER TOOL CHARACTERIZATION TEST

CONSTANT CURRENT CHARGE - 1.50 Amps • 21.8 V Cutoff • 20 C
 CYCLE # 2 DATE: OCTOBER 7, 1982 BATTERY SN: 1857

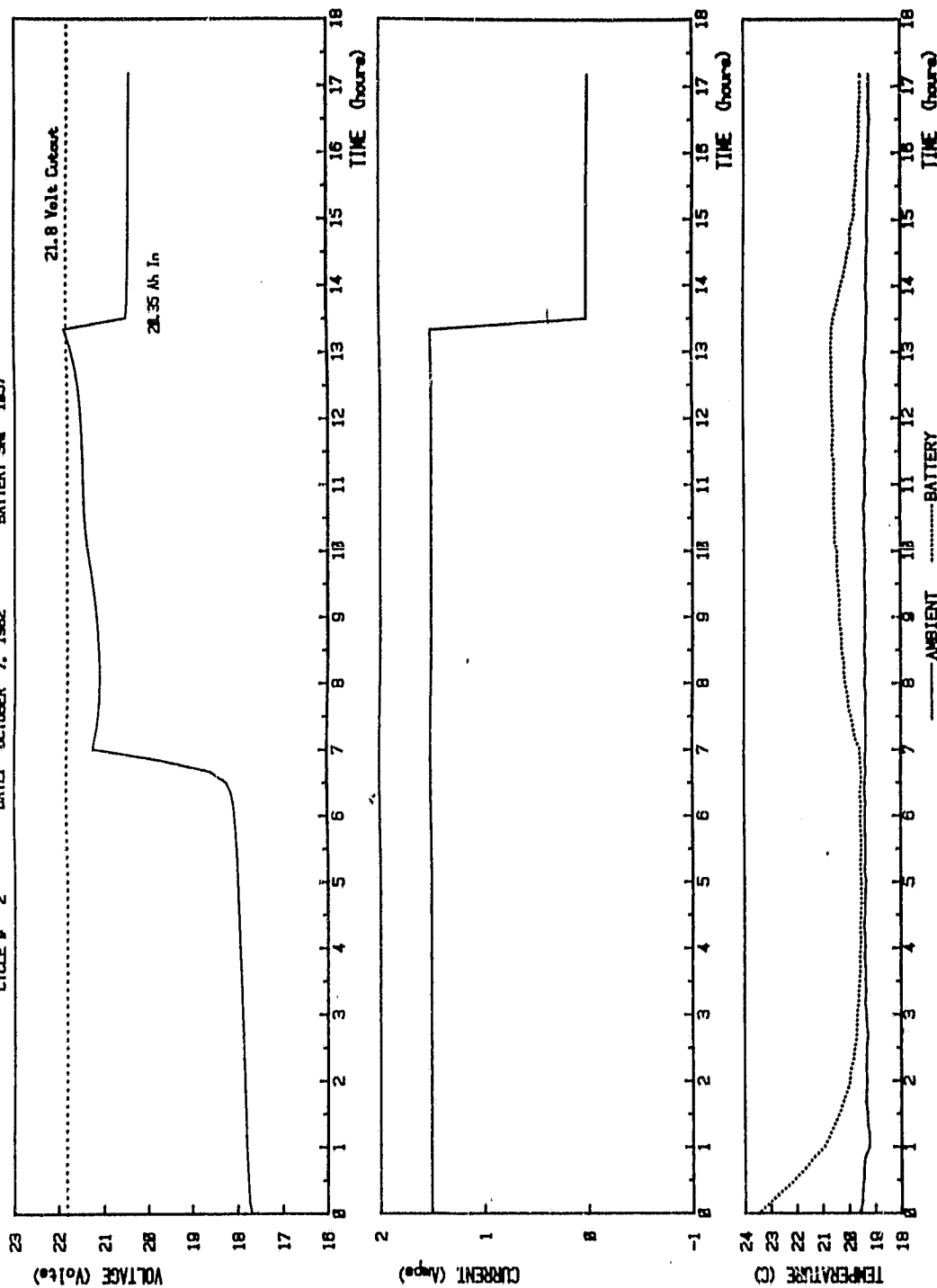


Figure 8. 1.5 Amp Charge, Cycle 2.

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Figure 9 shows the last recharge performed during this study. The recharge capacity was 28.8 ah, 15 percent more than the nominal rated capacity. There was a significant change in the battery voltage characteristic during the 7 battery recharges which followed each 100% DOD. Early in the cycling regime, 50 percent of the recharge occurred at the monovalent (Ag_2O) voltage level; whereas 82 percent of the final recharge occurred at the higher divalent (Ag_2O_2) voltage level. The argentic voltage characteristic gradually increased thru-out the charge regime. Similar results were also observed during the discharge regime and will be discussed in the next section of this document.

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EMU BATTERY / SMM POWER TOOL CHARACTERIZATION TEST

CONSTANT CURRENT CHARGE - 1.50 Amps, 21.8 V Cutout, 28 C
CYCLE # 8 DATE: NOVEMBER 9, 1982 BATTERY SN: 1857

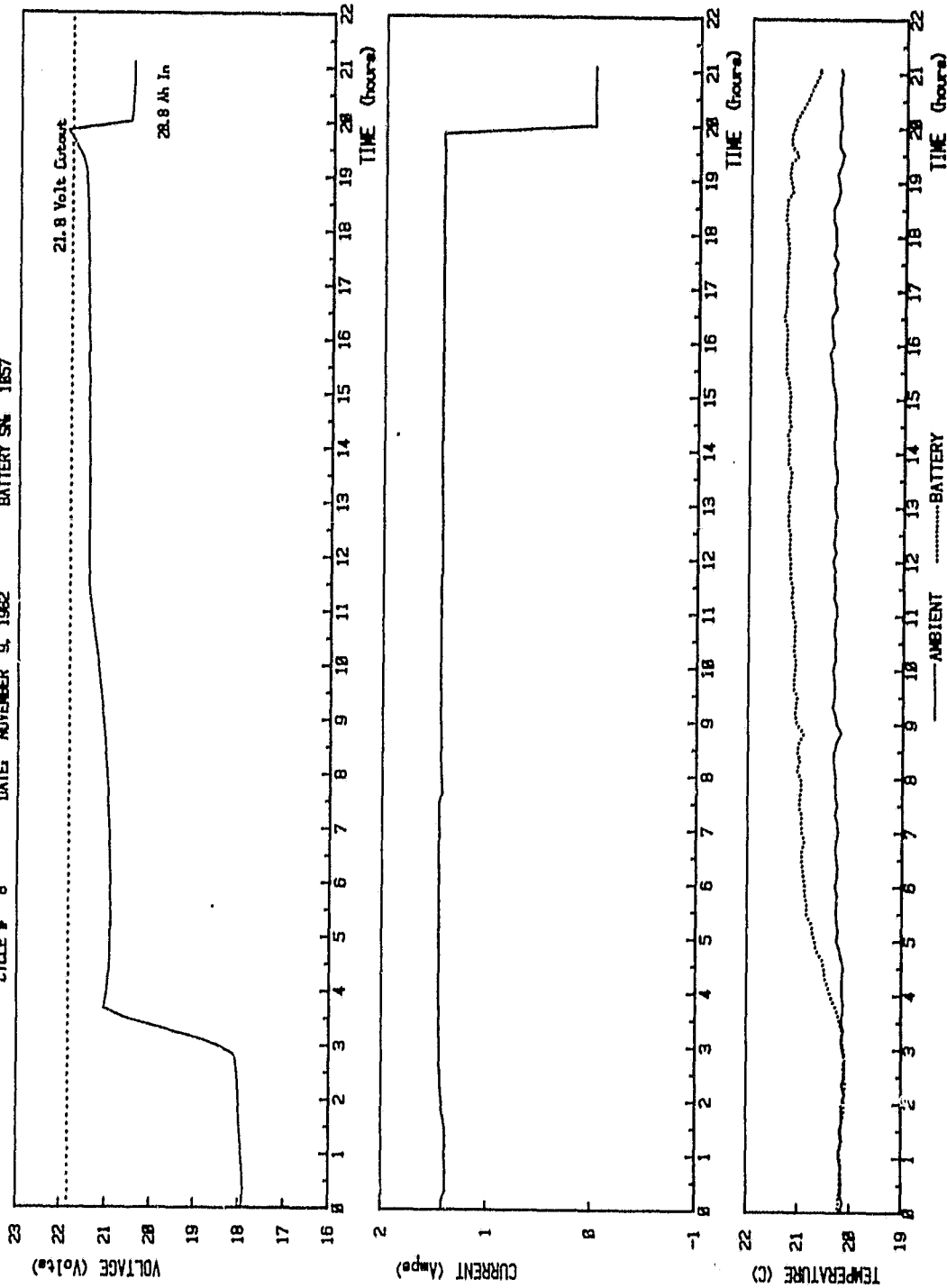


Figure 9. 1.5 Amp Charge, Cycle 8.

EMU DISCHARGE CHARACTERIZATION TESTS

The first discharge (cycle 1) was performed at 20°C ambient temperature in order to establish the baseline voltage characteristics and battery capacity after the 7 month stand period, since the 3 previous cycles and recharge were accomplished at room temperature ambient. The capacity output was substantially greater than the pre-shipping recharge capacity because the battery had not been discharged to 100% DOD during the initial 3 cycles. Figure 10 is a plot of the entire discharge and Figures 10.1 and 10.2 show the first and last sequential pulse regimes during this discharge.

Due to the exothermic reaction within the battery cells, battery temperature gradually increased 5 to 7 degrees above the ambient temperature. The battery voltage during this 20°C discharge was slightly lower than the voltages observed during cycle 2 at 10°C (Figures 11-11.2) and cycle 5, also at 20°C. The long charge stand appears to have also caused a slight degradation to the discharge voltage as well as charge capacity discussed previously. Battery voltage during the first hour of discharge for cycle 8 at 20°C (Figures 16-16.2) was substantially higher due to the gradual increase of Ag_2O_2 which occurred thru-out this study.

There was a significant decrease in battery voltage during the 0°C discharge (Figures 12-12.2) and a severe decrease at -10°C (Figures 13-13.2). There was also a decrease in discharge capacity at the lower temperatures due to the inefficiency of the electro-chemical reactions within the battery cells. If the power tool requires a higher operating voltage than the 12.0 cutout (i.e. 14.0 volts) a substantial decrease in battery capacity at -10°C would result.

A residual capacity of 7.6 ah accumulated during the low temperature thermal tests, which resulted in the high discharge capacity achieved during cycle 5, 20°C and the corresponding 139% discharge efficiency listed in Summary Table 1. Battery voltage, capacity and ampere-hour efficiency increased whenever the battery was discharged at the higher ambient temperatures (Figures 14-14.2, 15-15.2). The discharge capacity at 20°C for cycles 5 and 8 were similar, therefore the loss of

active Zn material in the negative electrodes was minimal after the first several cycles initiated in February 1982, prior to the 7 month stand.

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EMU BATTERY / 500W POWER TOOL CHARACTERIZATION TEST

LOAD SIMULATION - 3.5 Amp C.C. & 15.0 Amp Pulse Load. 12.0 V Cutout. 20 C
CYCLE # 1 DATE OCTOBER 7, 1982 BATTERY SN 1257

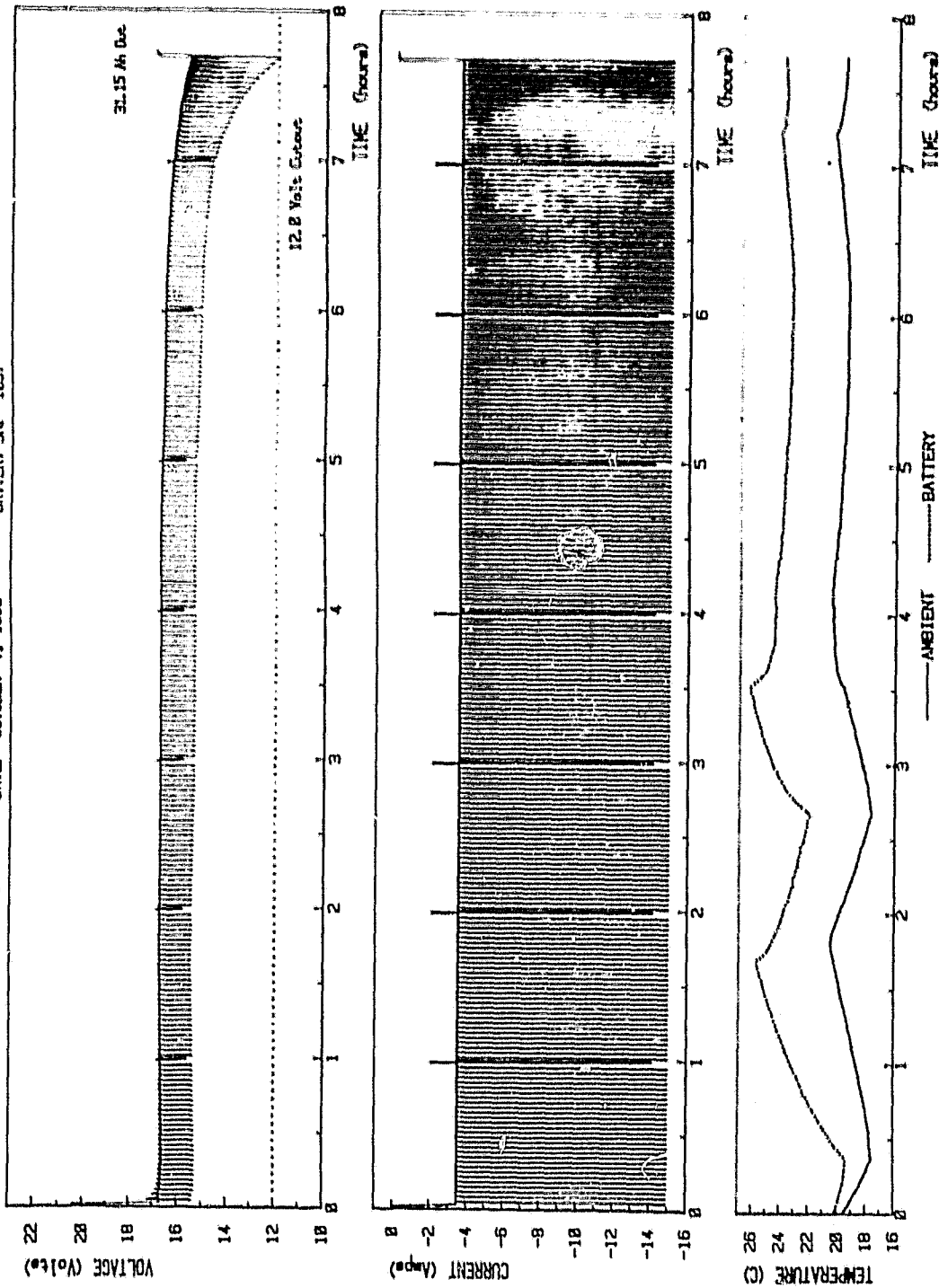
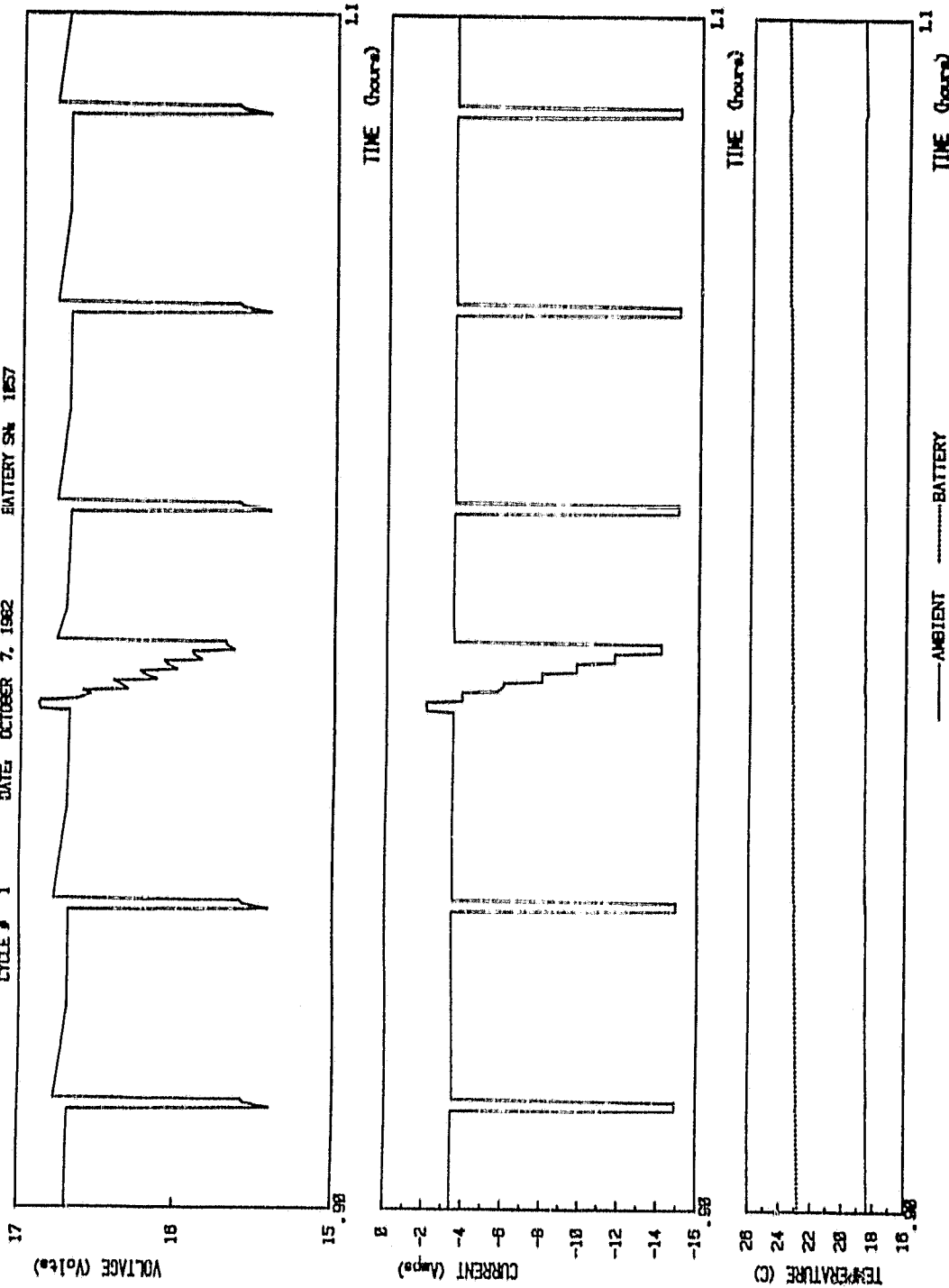


Figure 10. 20°C Discharge Characterization Test.

EMU BATTERY / SMM POWER TOOL CHARACTERIZATION TEST

LOAD SIMULATION - 3.5 Amp C.C. & 15.0 Amp Pulse Load . 12.0 V Cutoff . 20 C
 CYCLE # 1 DATE OCTOBER 7, 1982 BATTERY SN 1157



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Figure 10.1. First Sequential Pulse Regime At 20°C.

EMU BATTERY / SMM POWER TOOL CHARACTERIZATION TEST

LOAD SIMULATION - 3.5 Amp C.C. & 15.0 Amp Pulse Load, 12.0 V Cutout, 20 C
CYCLE # 1 DATE: OCTOBER 7, 1982 BATTERY SN: 1057

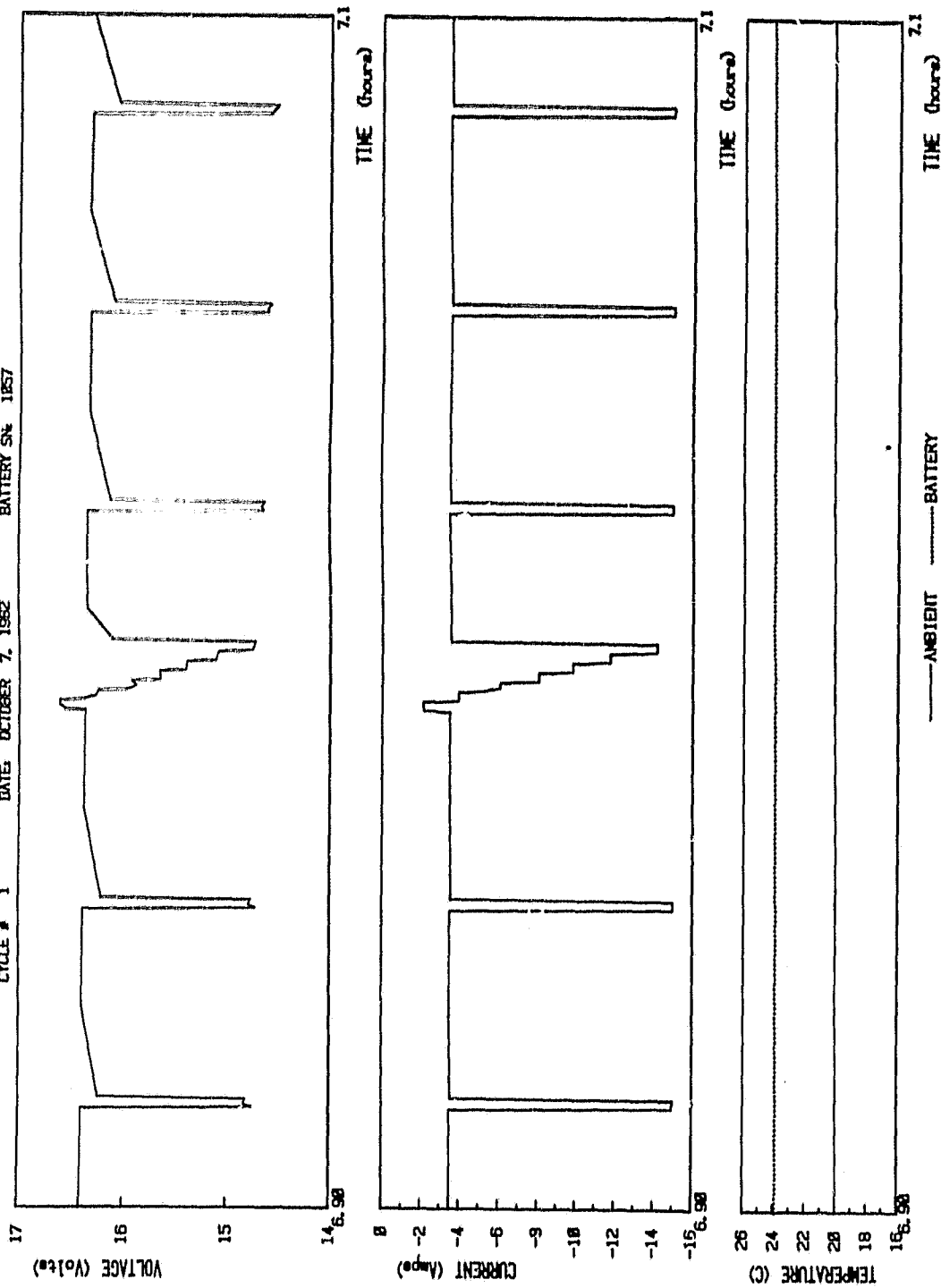
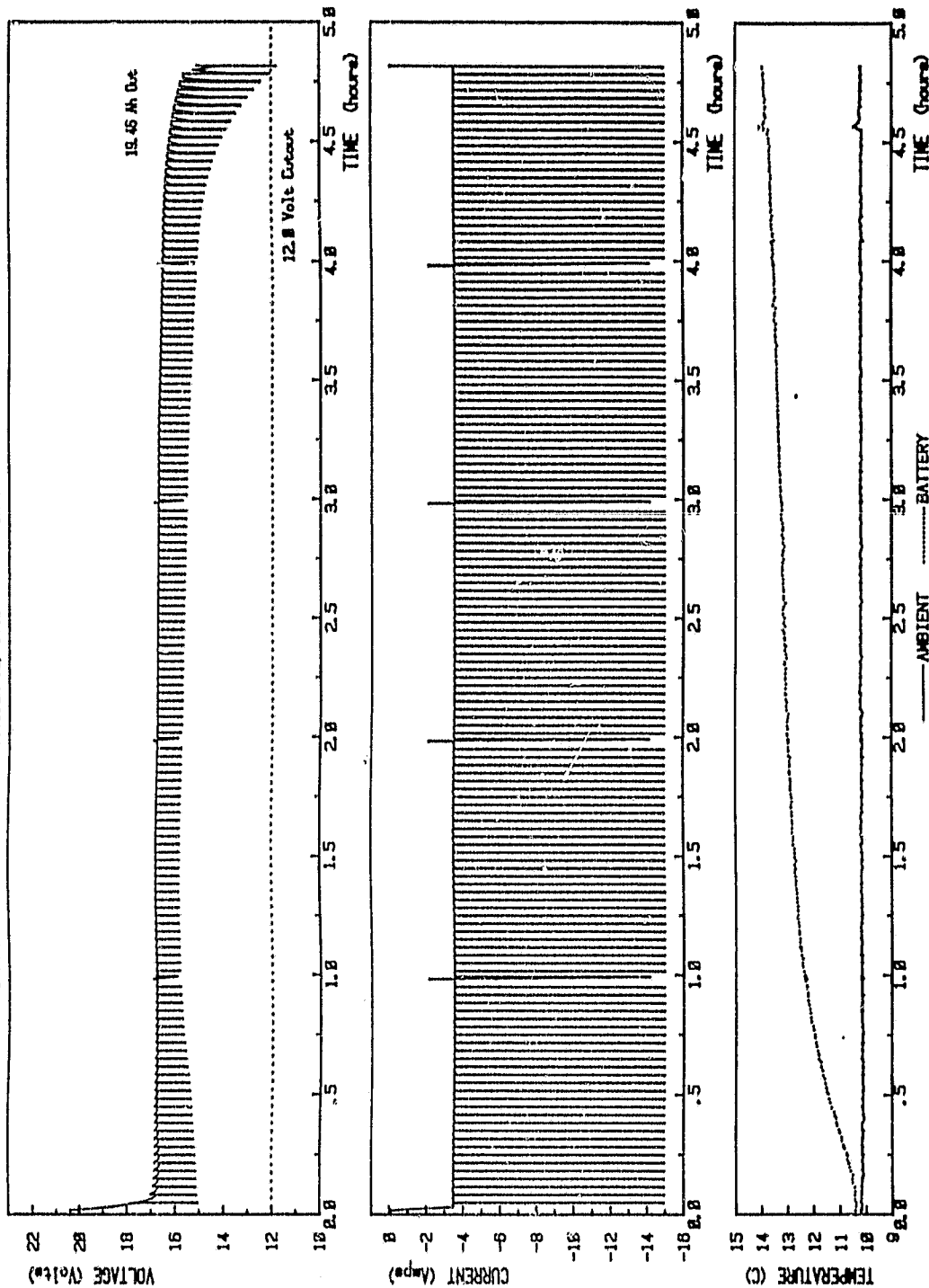


Figure 10.2. Last Sequential Pulse Regime At 20°C.

EMU BATTERY / SMM POWER TOOL CHARACTERIZATION TEST

LOAD SIMULATION - 3.5 Amp C.C. & 15.0 Amp Pulse Load, 12.0 V Cutoff, 10 C
 CYCLE # 2 DATE: OCTOBER 12, 1982 BATTERY SN 1857



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Figure 11. 10°C Discharge Characterization Test.

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EMU BATTERY / SMM POWER TOOL CHARACTERIZATION TEST

LOAD SIMULATION - 3.5 Amp C.C. & 15.0 Amp Pulse Load - 12.0 V Cutout - 10 C
CYCLE # 2 DATE: OCTOBER 12, 1982 BATTERY SN: 1057

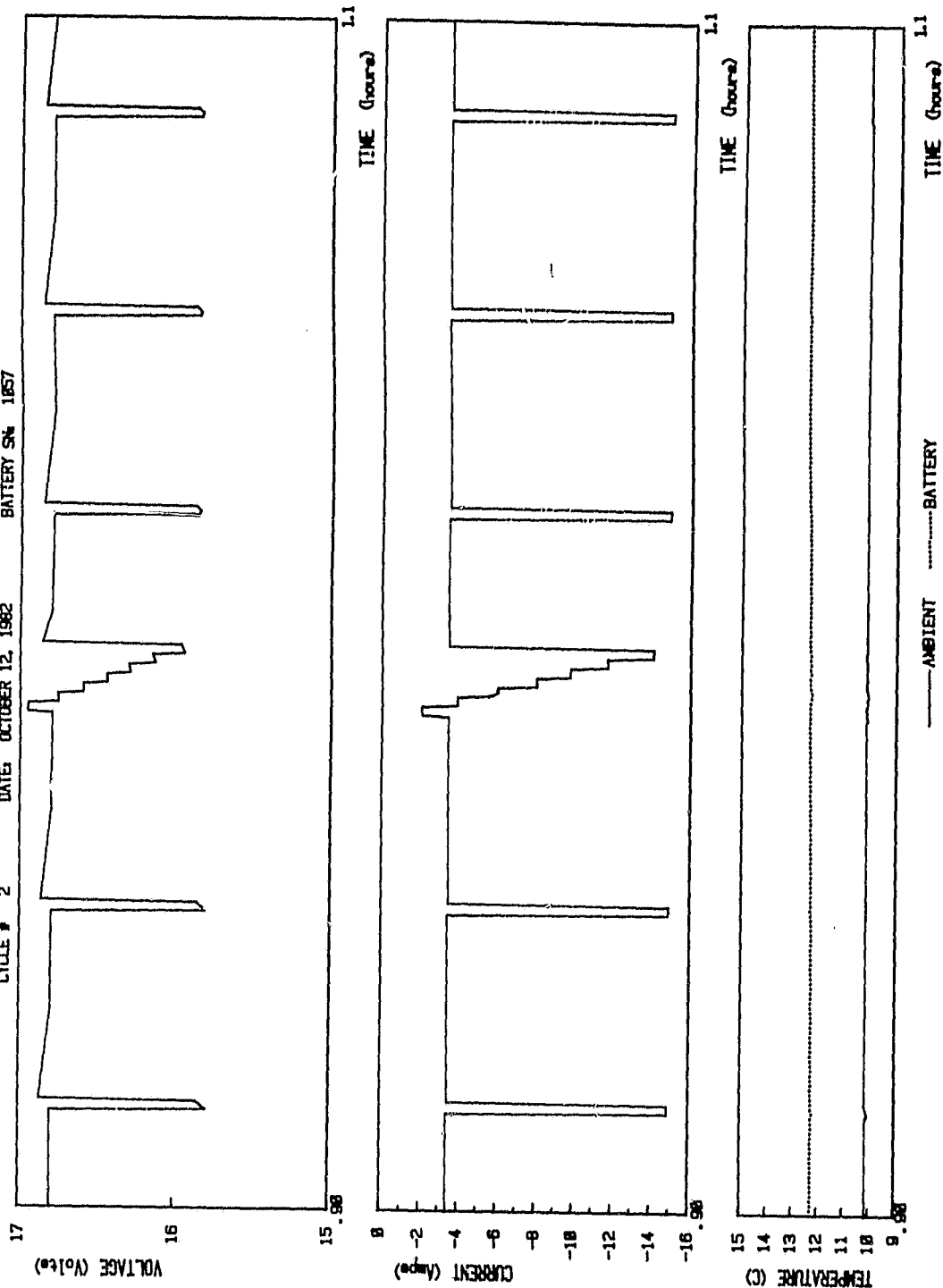


Figure 11.1 First Sequential Pulse Regime At 10°C.

EMU BATTERY / SMM POWER TOOL CHARACTERIZATION TEST

LOAD SIMULATION - 3.5 Amp C.C. & 15.0 Amp Pulse Load . 12.0 V Cutoff , 10 C
 CYCLE # 2 DATE: OCTOBER 12, 1982 BATTERY SN# 1057

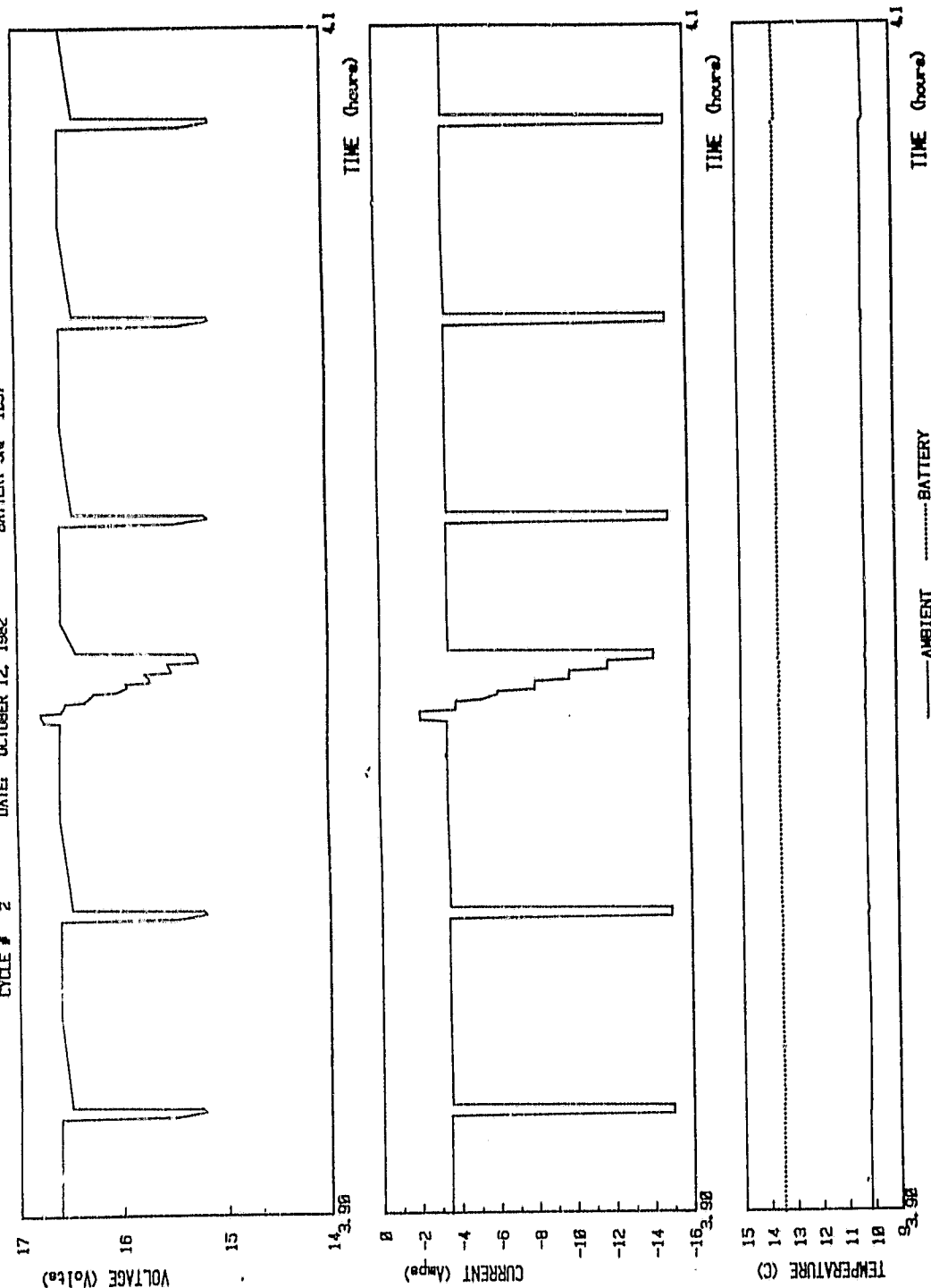


Figure 11.2. Last Sequential Pulse Regime At 10°C.

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EMU BATTERY / SMM POWER TOOL CHARACTERIZATION TEST

LOAD SIMULATION - 3.5 Amp C.C. & 15.0 Amp Pulse Load . 12.0 V Cutout . 0 C
 CYCLE # 3 DATE: OCTOBER 14, 1982 BATTERY SN 1857

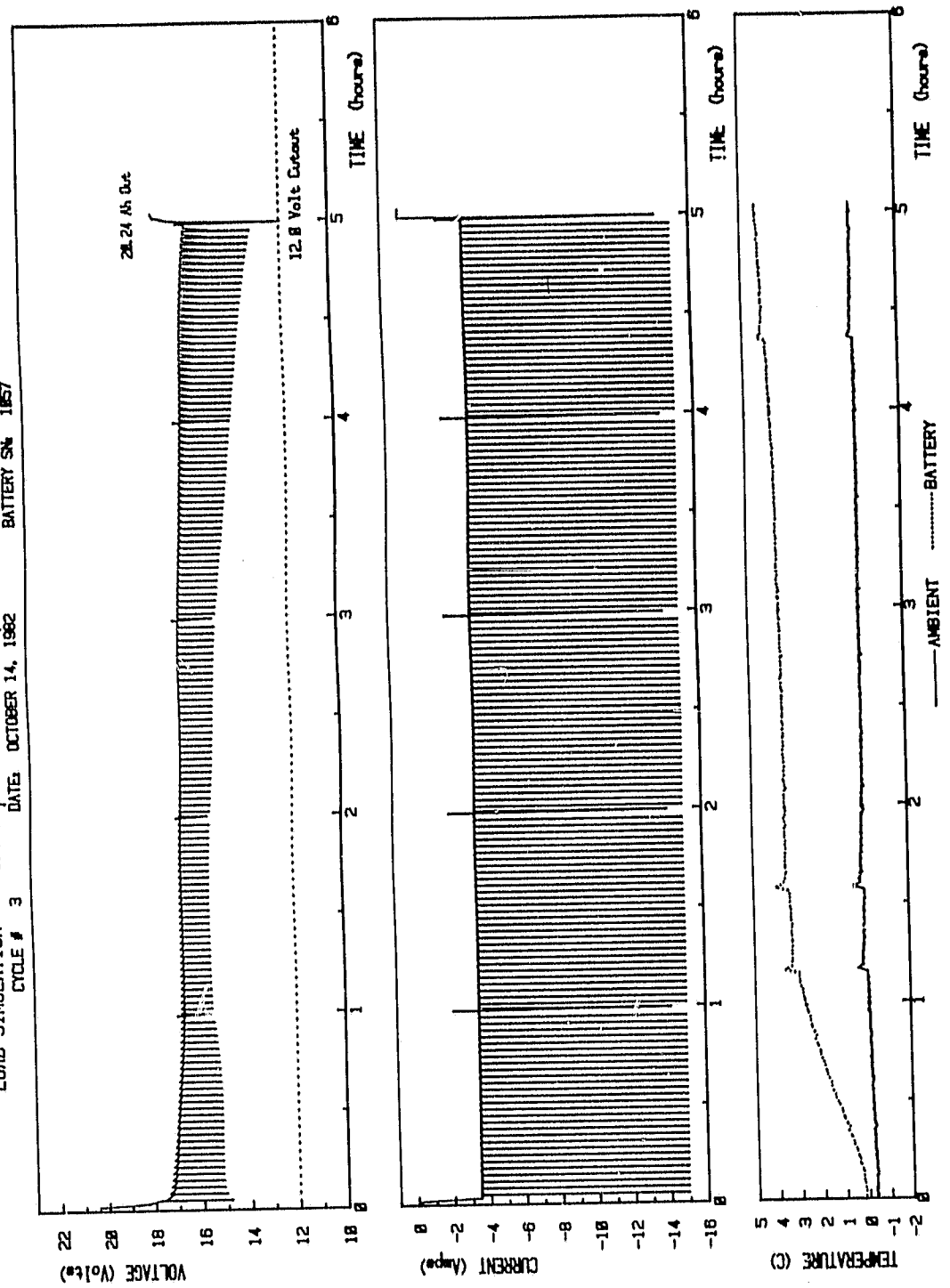


Figure 12. 0°C Discharge Characterization Test.

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EMU BATTERY / SMM POWER TOOL CHARACTERIZATION TEST

LOAD SIMULATION - 3.5 Amp C.C. & 15.0 Amp Pulse Load - 12.0 V Cutoff - 0 C
 CYCLE # 3 DATE: OCTOBER 14, 1982 BATTERY SN: 1057

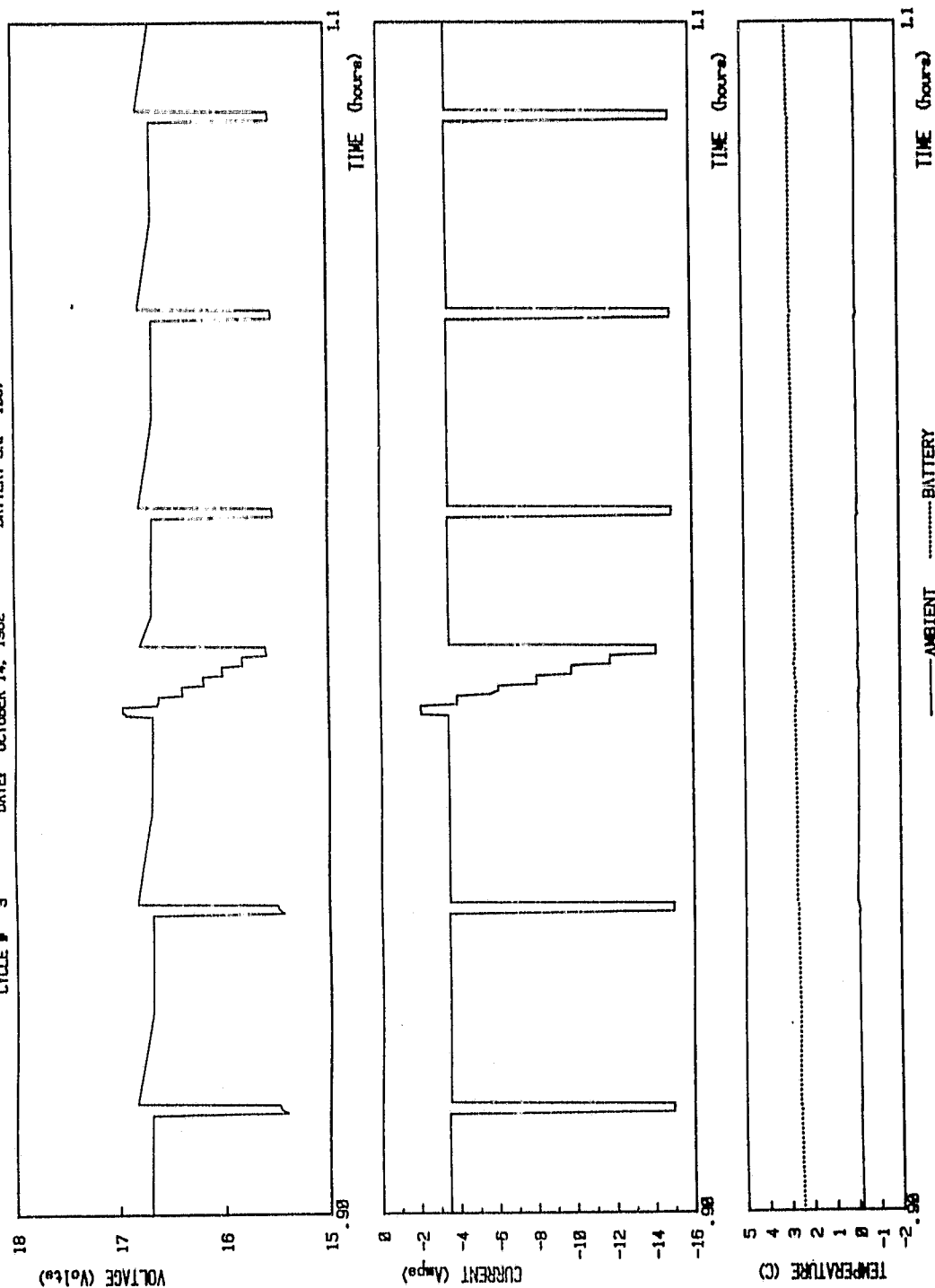


Figure 12.1. First Sequential Pulse Regime At 0°C.

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EMU BATTERY / SMM POWER TOOL CHARACTERIZATION TEST

LOAD SIMULATION - 3.5 Amp C.C. & 15.0 Amp Pulse Load . 12.0 V Cutoff . 0 C
CYCLE # 3 DATE: OCTOBER 14, 1982 BATTERY SN: 1857

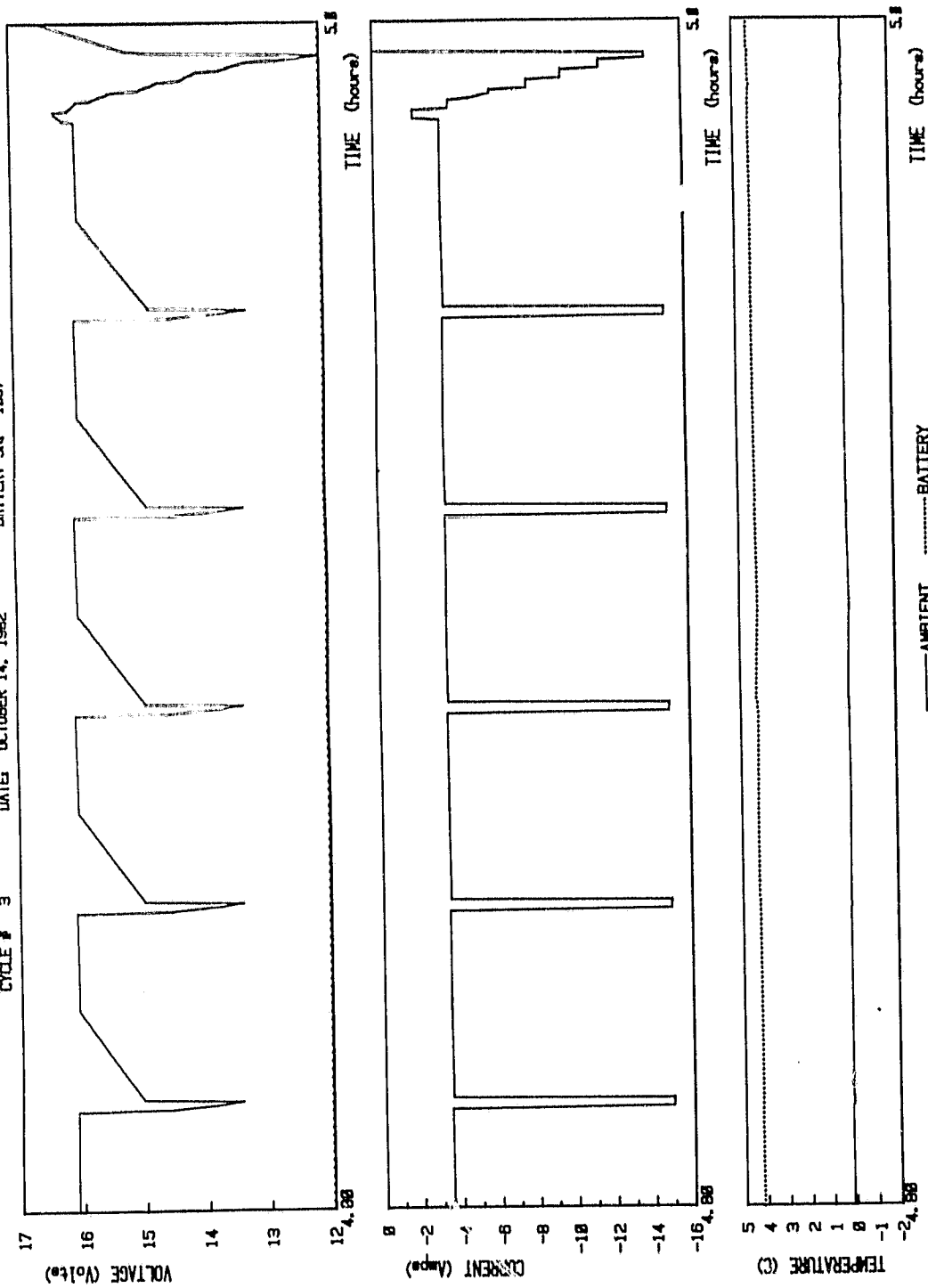
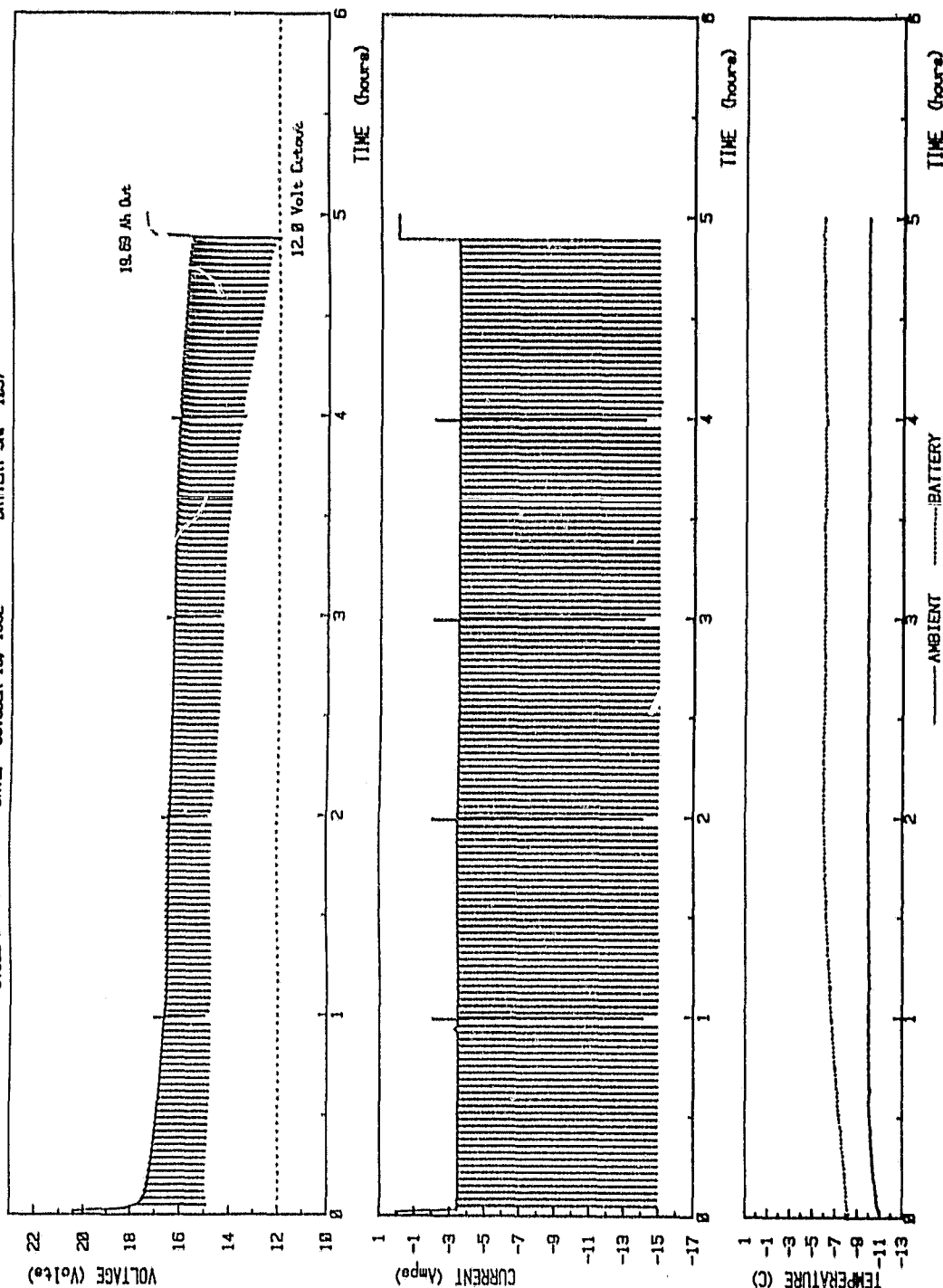


Figure 12.2. Last Sequential Pulse Regime At 0°C.

EMU BATTERY / SMM POWER TOOL CHARACTERIZATION TEST

LOAD SIMULATION - 3.5 Amp C.C. & 15.0 Amp Pulse Load, 12.0 V Cutout, -10°C
 CYCLE # 4 DATE: OCTOBER 19, 1982 BATTERY SN: 1857



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Figure 13. -10°C Discharge Characterization Test.

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EMU BATTERY / SMM POWER TOOL CHARACTERIZATION TEST

LOAD SIMULATION - 3.5 Amp C.C. & 15.0 Amp Pulse Load, 12.0 V Cutout, -10°C
CYCLE # 4 DATE: OCTOBER 19, 1982 BATTERY SN: 1257

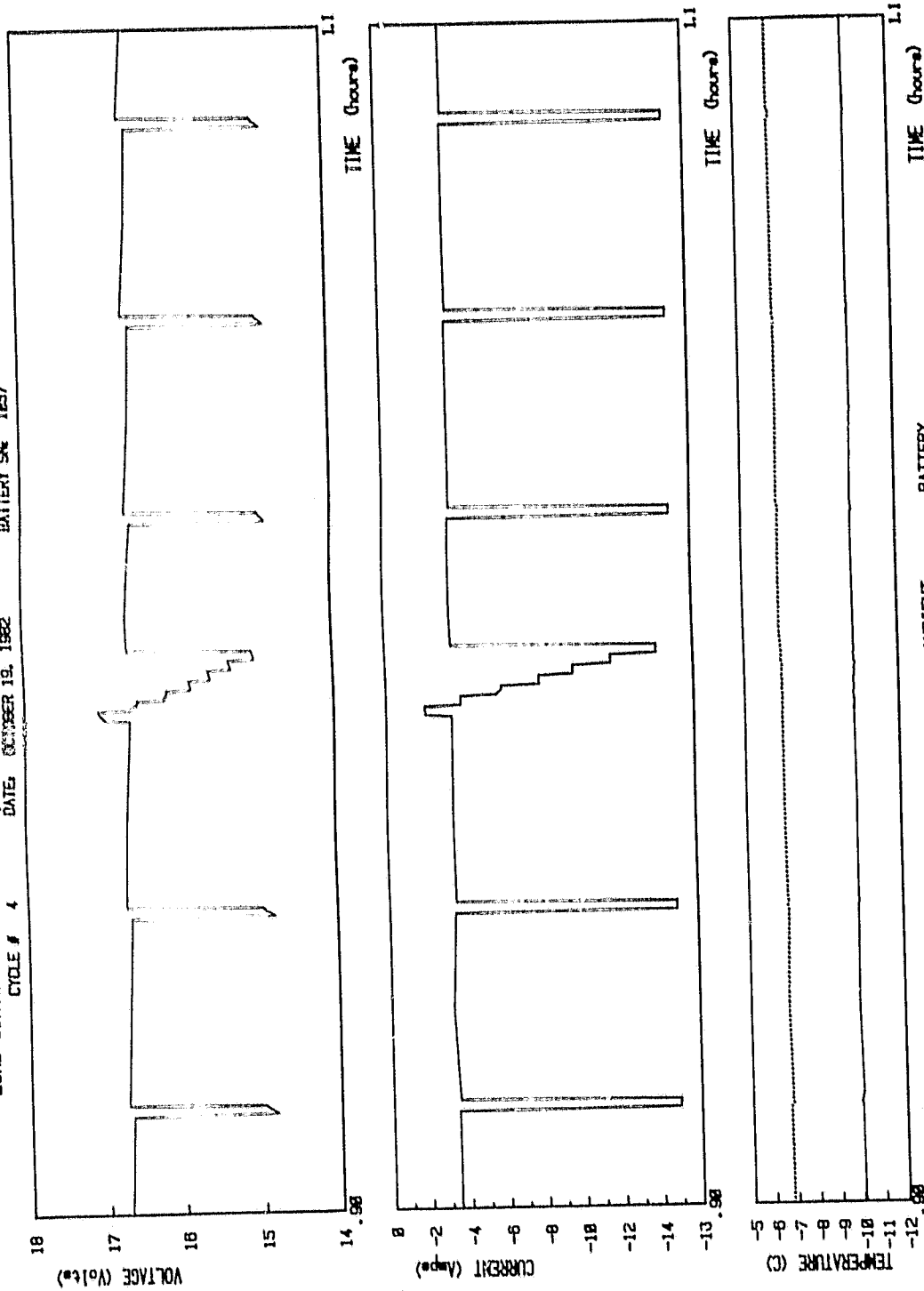


Figure 13.1. First Sequential Pulse Regime At -10°C.

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EMU BATTERY / SMM POWER TOOL CHARACTERIZATION TEST

LOAD SIMULATION - 3.5 Amp C.C. & 15.0 Amp Pulse Load, 12.0 V Cutout, -10°C
CYCLE # 4 DATE: OCTOBER 19, 1982 BATTERY SN: 1857

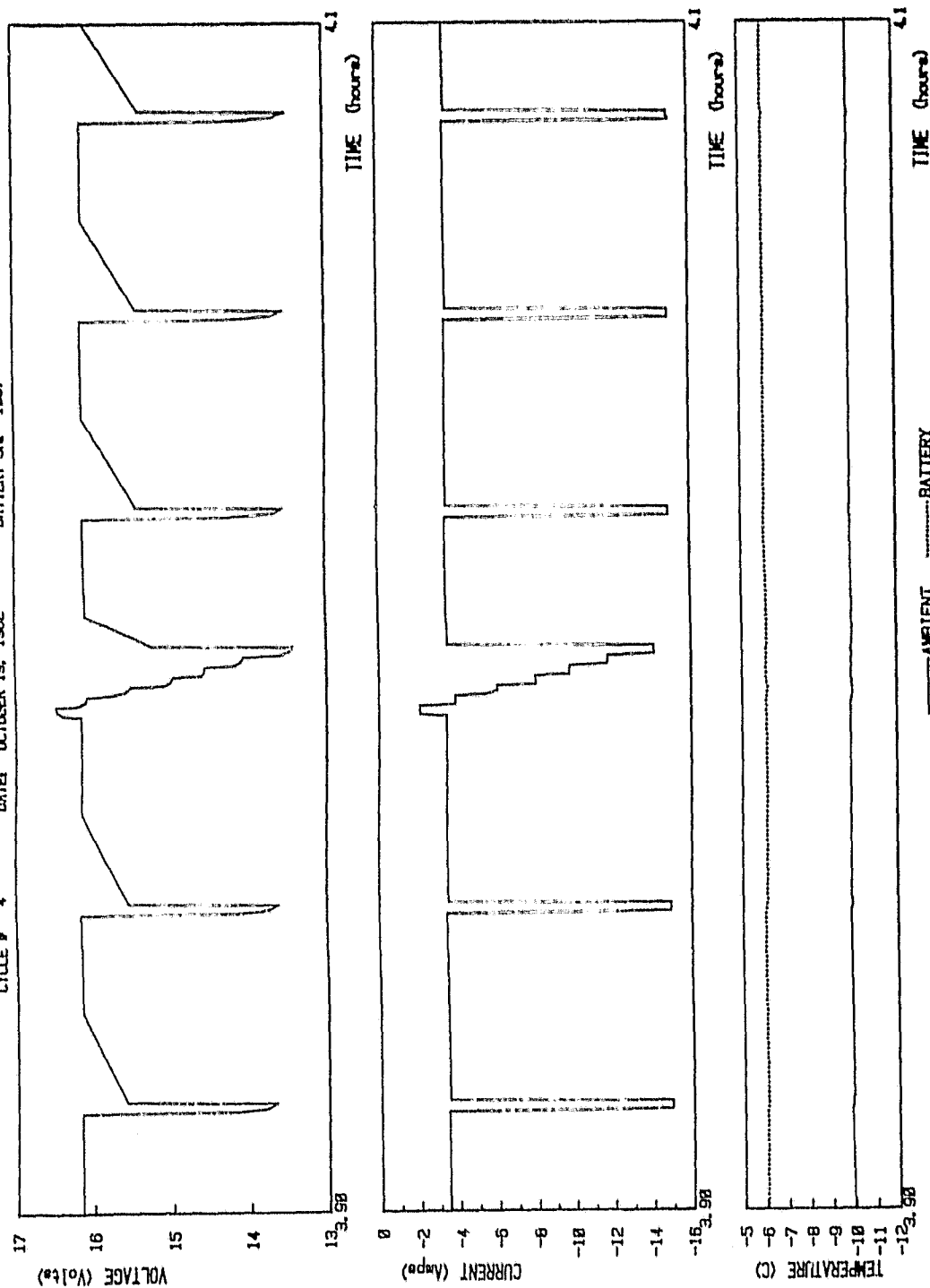


Figure 13.2. Last Sequential Pulse Regime At -10°C.

Table 1

SUMMARY OF EMU/SMM POWER TOOL CHARACTERIZATION TESTS

DATE	CYCLE FLIGHT LOAD TEST	CHARGE				DISCHARGE				EFFICIENCY	
		I	°C	Ah	Wh	DATE	°C	Ah	Wh	Ah	Wh
2-28-82								24.75			
3-2-82	PRE SHIPPING RECHG.			24.75							
10-6-82	1	1.0	20	0.21	4.7	10-7	20	31.15	511.5		
10-7-82	2	1.5	20	20.35	399.3	10-12	10	19.46	320.3	95.6	80.2
10-12-82	3	1.0 1.5	20	*23.72	470.4	10-14	0	20.24	329.3	85.3	70.0
10-18-82	4	1.5	20	*24.87	596.4	10-19	-10	19.69	315.2	79.2	62.2
10-20-82	5	1.0	20	19.63	402.8	10-27	20	27.30	451.8	139.1	112.2
10-27-82	6	1.5	20	28.01	571.0	11-4	30	28.36	474.8	101.2	83.2
11-4-82	7	1.5	20	30.03	619.0	11-8	40	30.30	515.3	100.9	83.2
11-9-82	8	1.5	20	28.80	596.8	11-10	20	27.83	474.1	95.6	79.4
AVERAGE EFFICIENCY (CYCLES 2-8) = 99.7										71.2	

*MANUALLY STOPPED CHARGE BEFORE
VOLTAGE CUTOFF OCCURRED.

EMU BATTERY / SMM POWER TOOL CHARACTERIZATION TEST

LOAD SIMULATION - 3.5 Amp C.C. & 15.0 Amp Pulse Load, 12.0 V Cutout, 30 C
 CYCLE # 6 DATE NOVEMBER 4, 1982 BATTERY SN 1057

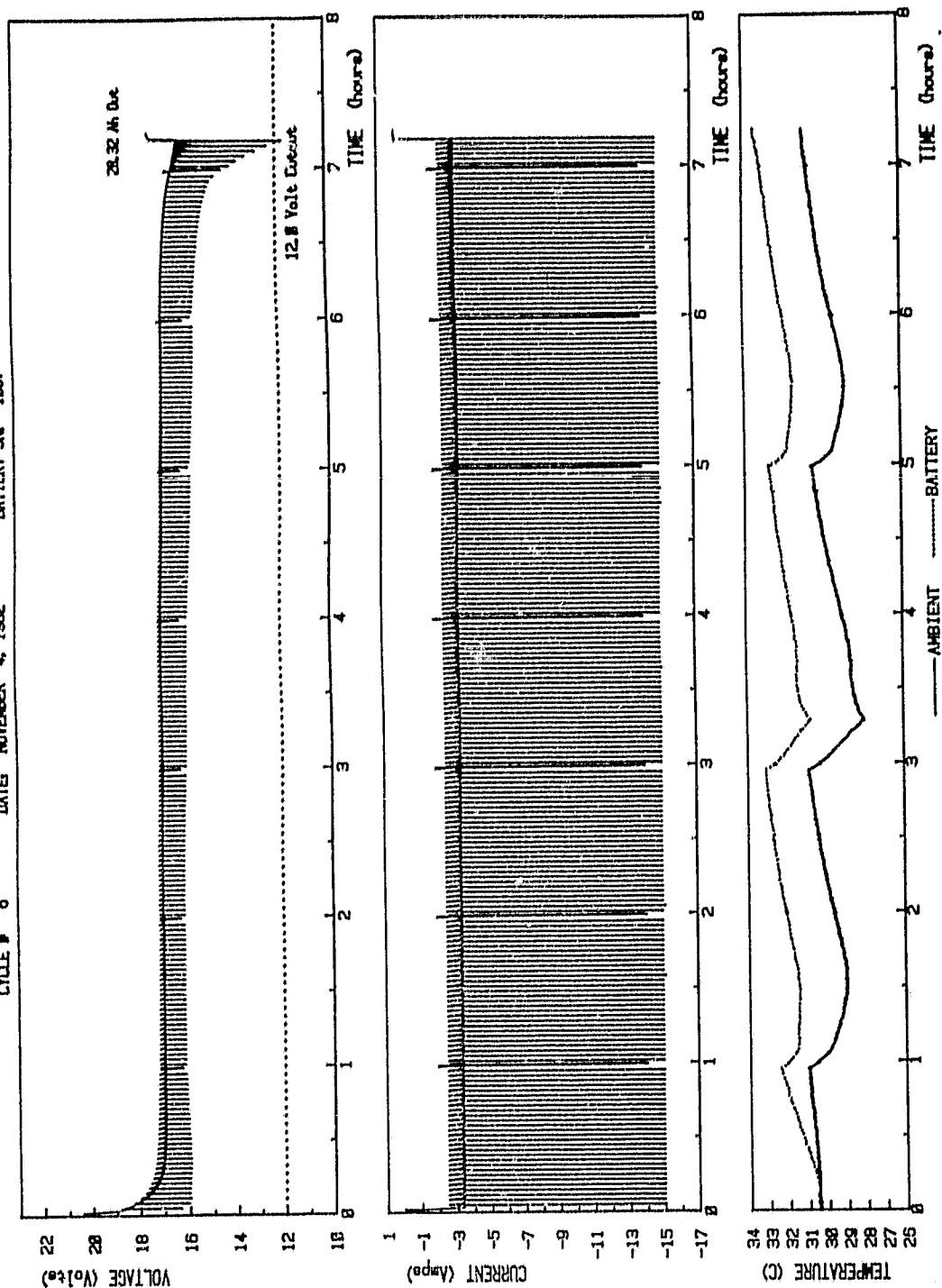
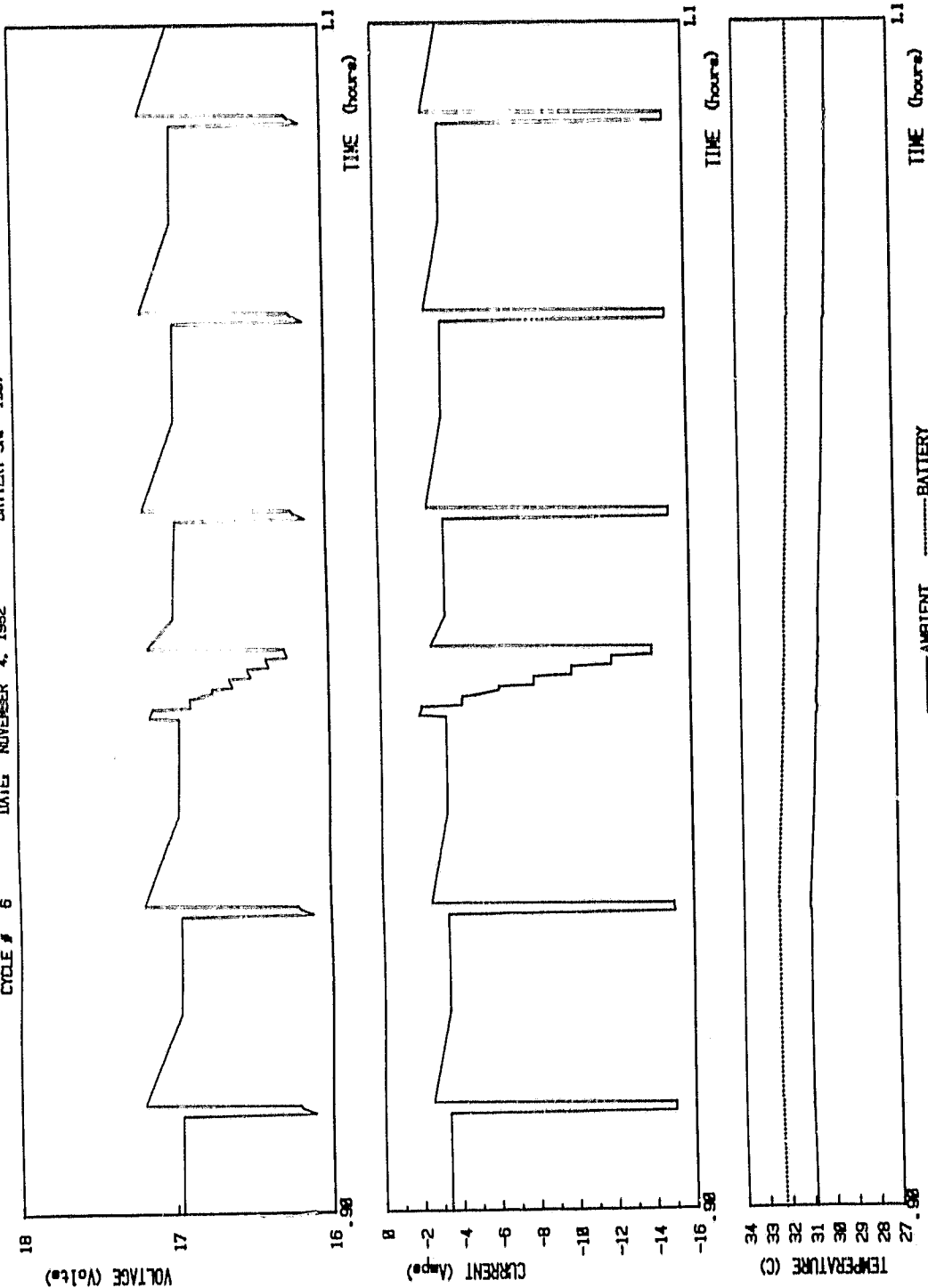


Figure 14. 30°C Discharge Characterization Test.

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EMU BATTERY / SMM POWER TOOL CHARACTERIZATION TEST

LOAD SIMULATION - 3.5 Amp C.C. & 15.0 Amp Pulse Load, 12.0 V Cutoff, 30 C
 CYCLE # 6 DATE: NOVEMBER 4, 1992 BATTERY SN: 1857



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Figure 14.1. First Sequential Pulse Regime At 30°C.

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EMU BATTERY / SMM POWER TOOL CHARACTERIZATION TEST

LOAD SIMULATION - 3.5 Amp C.C. & 15.0 Amp Pulse Load, 12.0 V Cutout, 30 C
CYCLE # 6 DATE: NOVEMBER 4, 1982 BATTERY SN# 1857

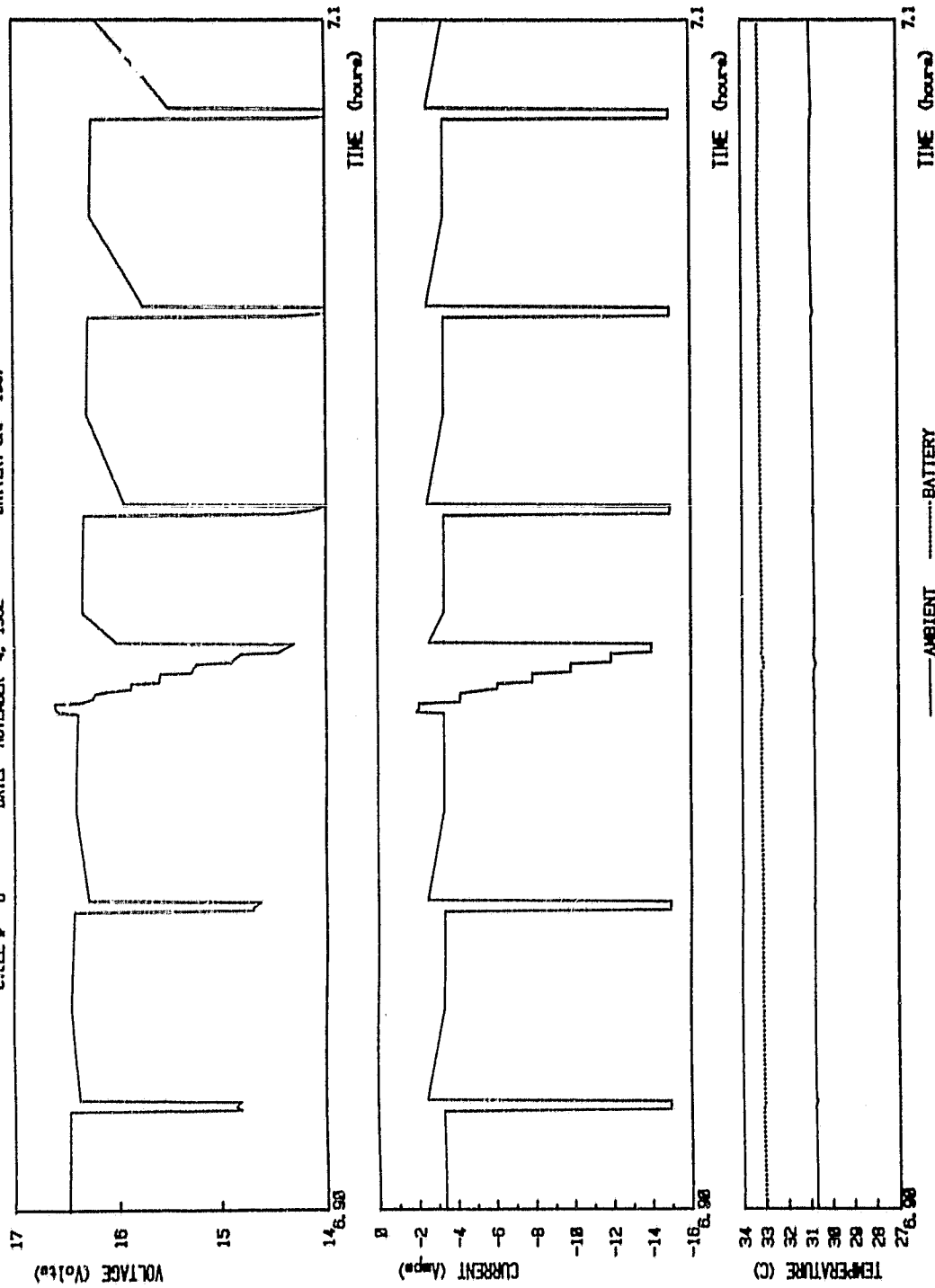


Figure 14.2. Last Sequential Pulse Regime At 30°C.

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EMU BATTERY / SMM POWER TOOL CHARACTERIZATION TEST

LOAD SIMULATION - 3.5 Amp C.C. & 15.0 Amp Pulse Load . 12.0 V Cutout . 48 C
CYCLE # 7 DATE: NOVEMBER 8, 1982 BATTERY SN: 1857

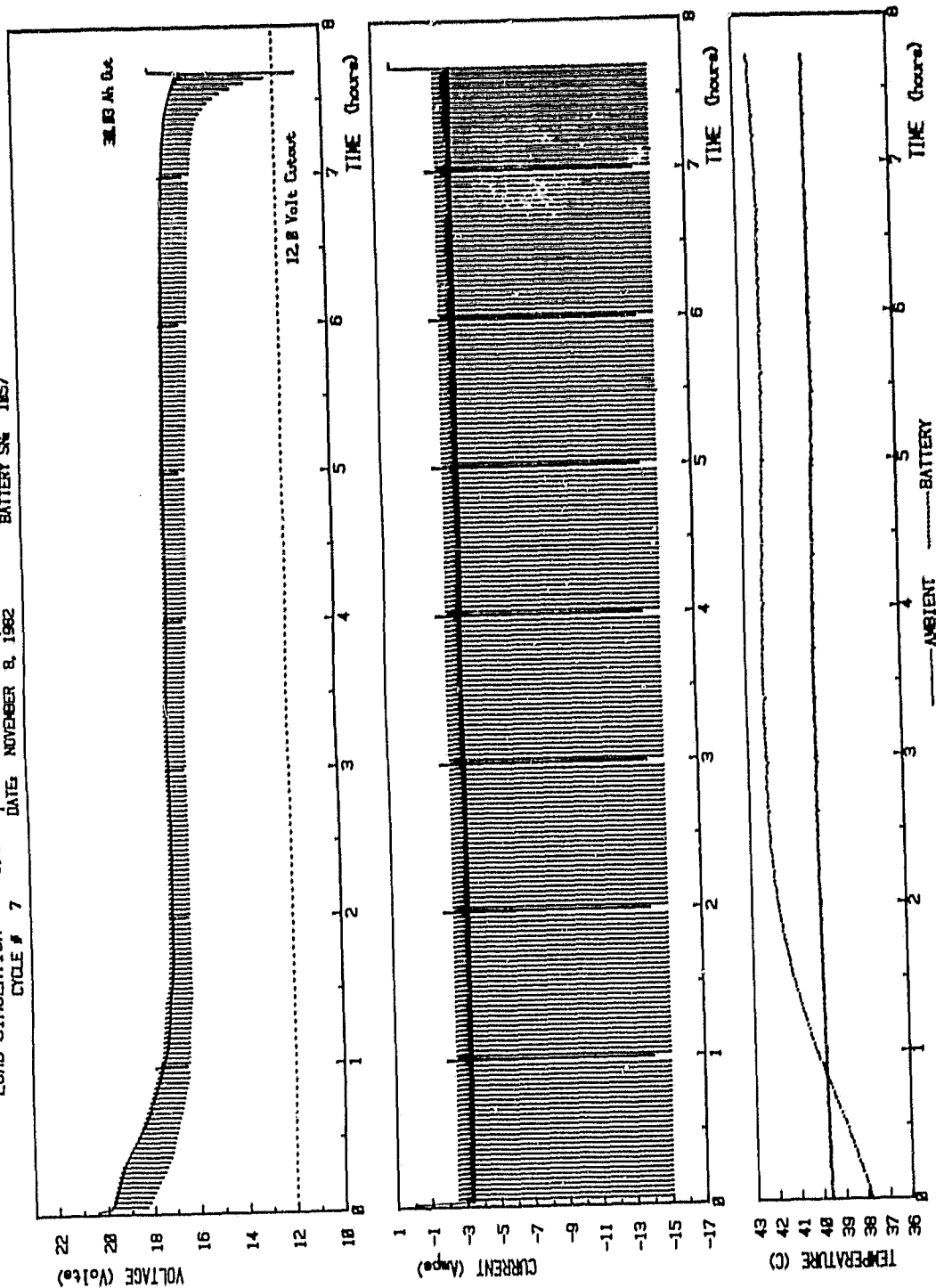


Figure 15. 40°C Discharge Characterization Test.

EMU BATTERY / SMM POWER TOOL CHARACTERIZATION TEST

LOAD SIMULATION - 3.5 Amp C.C. & 15.0 Amp Pulse Load, 12.0 V Cutout, 40 C
 CYCLE # 7 DATE: NOVEMBER 8, 1982 BATTERY SN# 1857

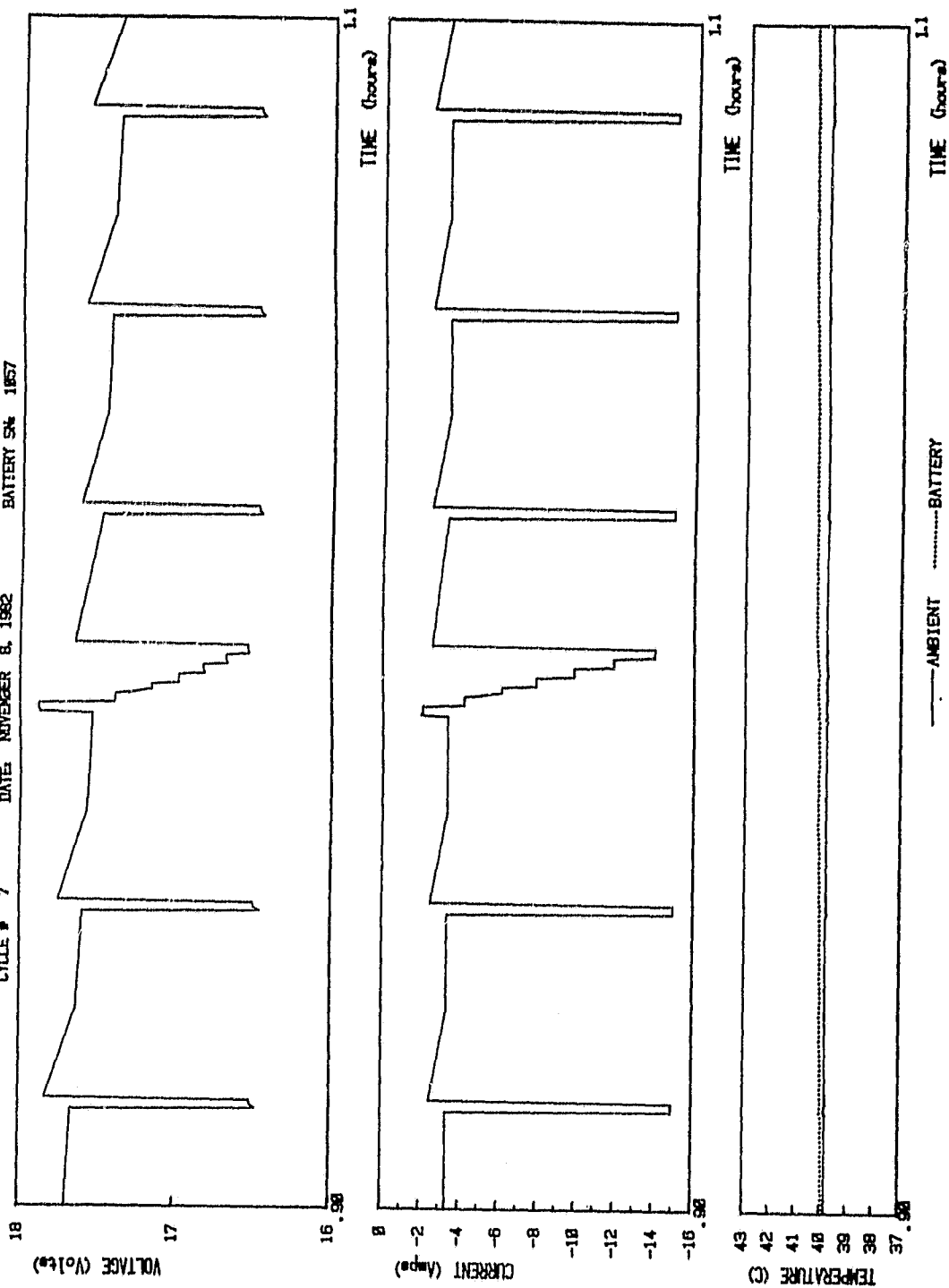


Figure 15.1. First Sequential Pulse Regime At 40°C.

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EMU BATTERY / SMM POWER TOOL CHARACTERIZATION TEST

LOAD SIMULATION - 3.5 Amp C.C. & 15.0 Amp Pulse Load, 12.0 V Cutout, 40 C
CYCLE # 7 DATE: NOVEMBER 8, 1982 BATTERY SN: 1057

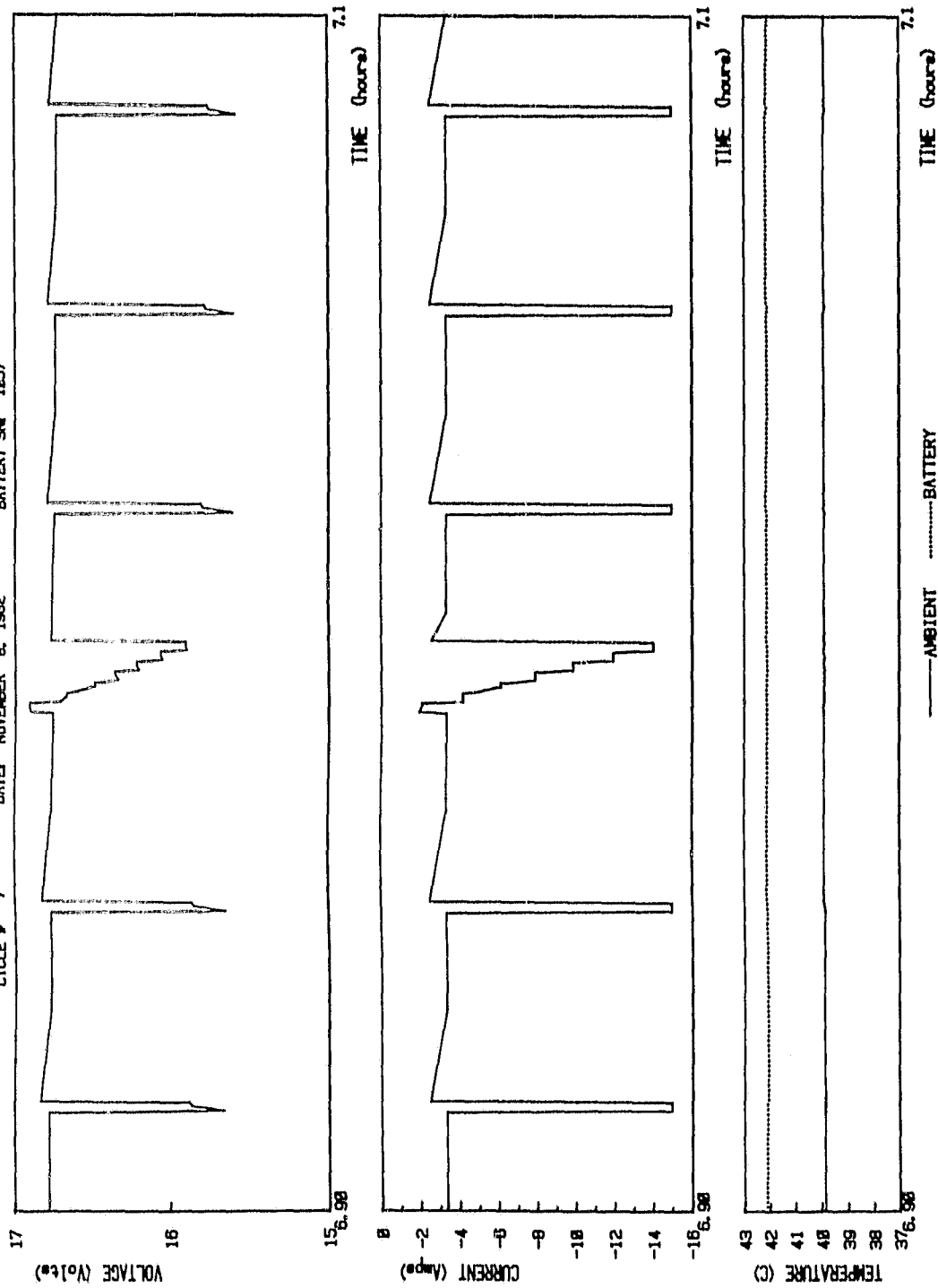


Figure 15.2. Last Sequential Pulse Regime At 40°C.

EMU BATTERY / SHM POWER TOOL CHARACTERIZATION TEST

LOAD SIMULATION - 3.5 Amp C.C. & 15.0 Amp Pulses Load, 12.0 V Cutoff, 20°C
CYCLE # 8 DATE NOVEMBER 18, 1982 BATTERY SN 1857

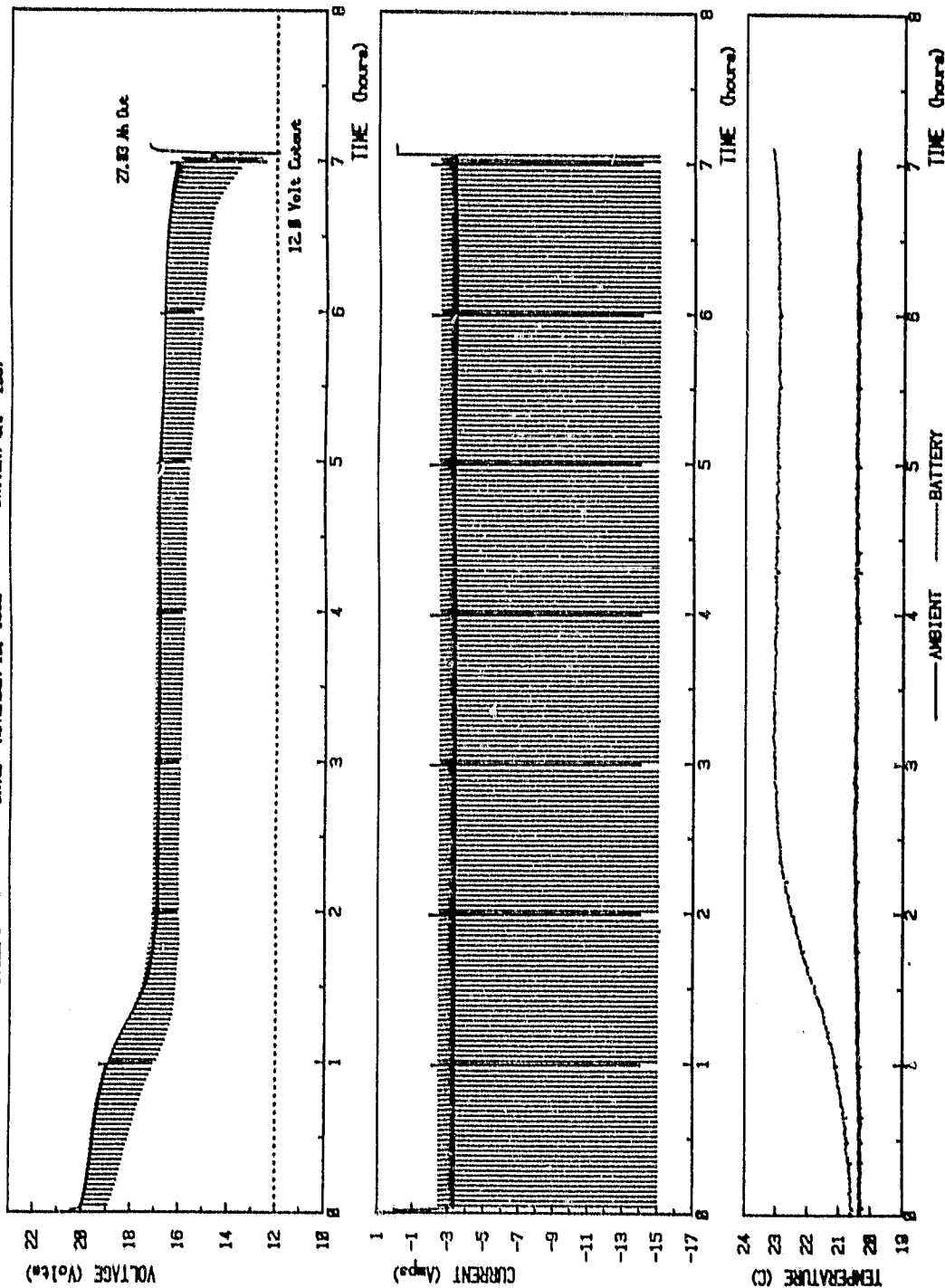


Figure 16. Final 20°C Discharge Characterization Test.

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EMU BATTERY / SMM POWER TOOL CHARACTERIZATION TEST

LOAD SIMULATION - 3.5 Amp C.C. & 15.0 Amp Pulse Load, 12.0 V Cutoff, 20 C
CYCLE # 8 DATE NOVEMBER 12, 1982 BATTERY SN 1857

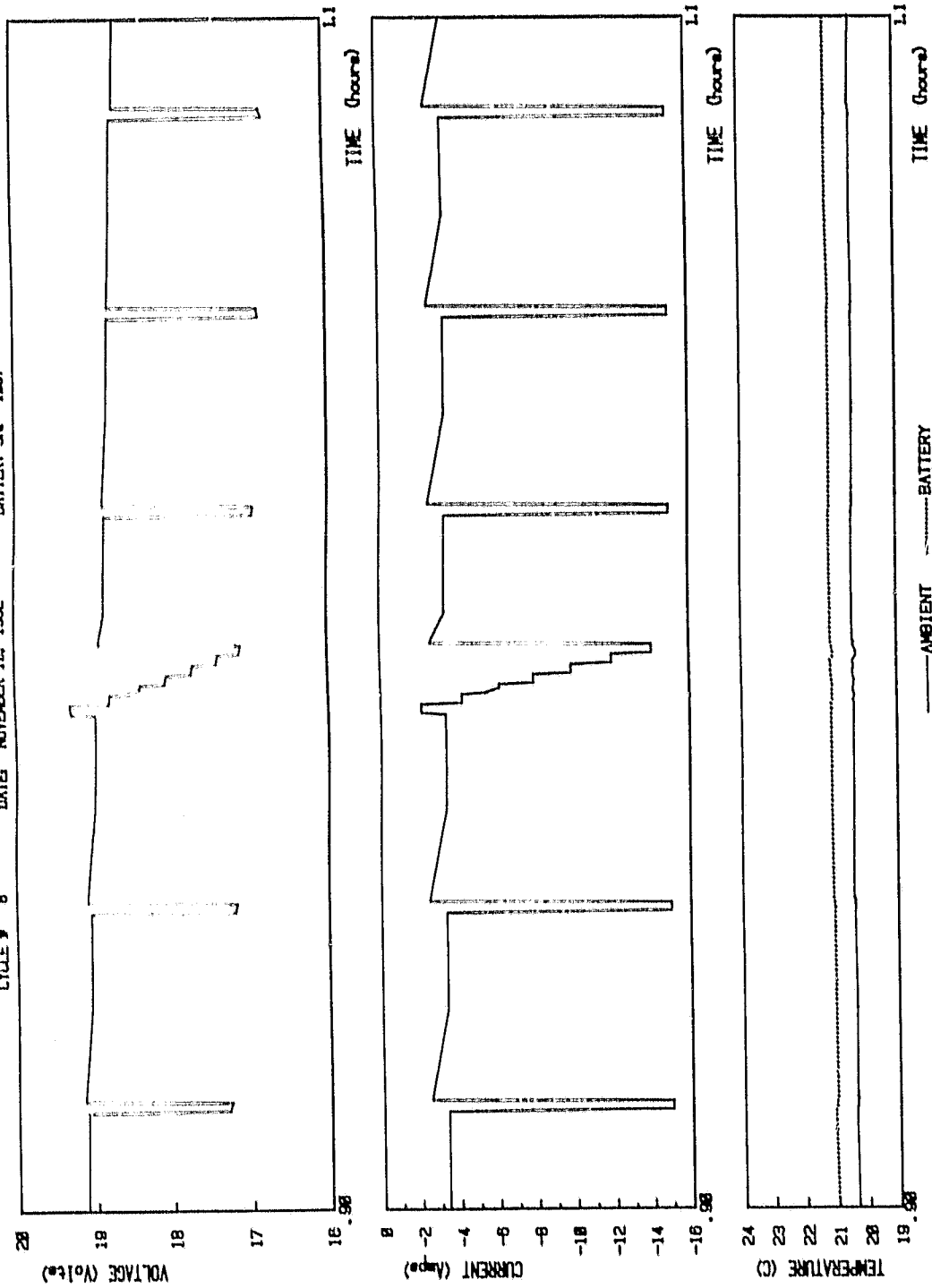


Figure 16.1. First Sequential Pulse Regime At 20°C.

EMU BATTERY / SMM POWER TOOL CHARACTERIZATION TEST

LOAD SIMULATION - 3.5 Amp C.C. & 15.0 Amp Pulse Load, 12.0 V Cutoff, 20 C
 CYCLE # 8 DATE: NOVEMBER 18, 1982 BATTERY SN: 1857

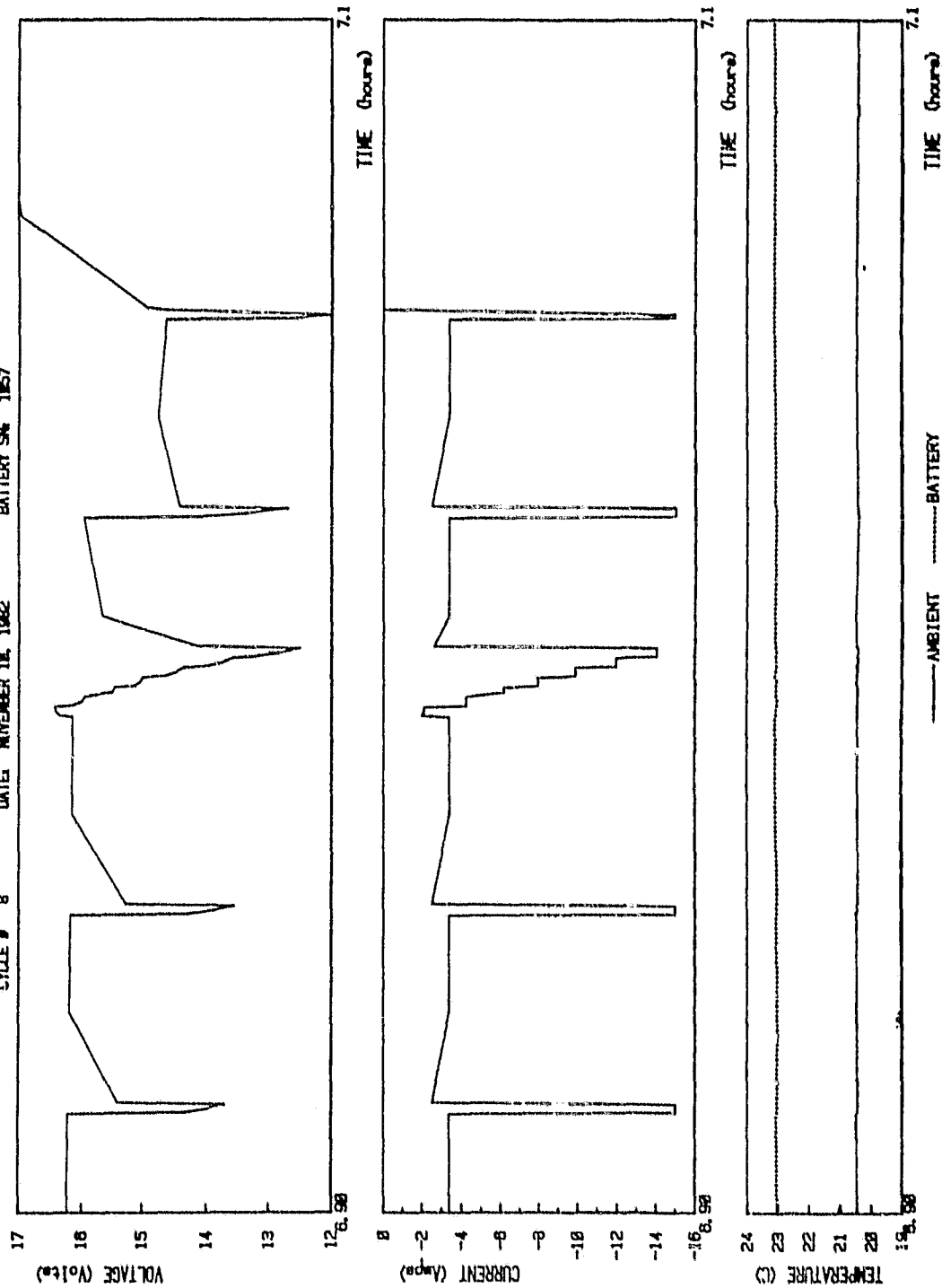


Figure 16.2. Last Sequential Pulse Regime At 20°C.

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CONCLUSIONS

The battery is capable of operating the power tool within the pulse current range of 2.0 amperes to 15.0 amperes and battery temperature range of -10°C to 40°C .

The "plateau" voltage which occurs when the silver electrodes are at the monovalent voltage level substantially decreases at the lower temperatures and higher pulse currents during the sequential pulse regime presented in Figure 17. The battery impedance ranged from 73 milli-ohms when battery temperature was 42°C and increased to 162 milli-ohms when battery temperature was -6.7°C . Figure 18 is a graph of the calculated battery impedance derived from the change in battery voltage (ΔV) which occurred at the various current levels during the sequential pulse regimes after the battery voltage stabilized at the monovalent potential.

Although the battery was capable of supporting numerous simulated "stall time/full speed" power tool operations at all temperature levels, the number of power tool operations will be reduced at sub zero temperatures if the power tool requires a higher operating voltage than the 12.0 volt cut-out used to terminate all discharges thru-out this study.

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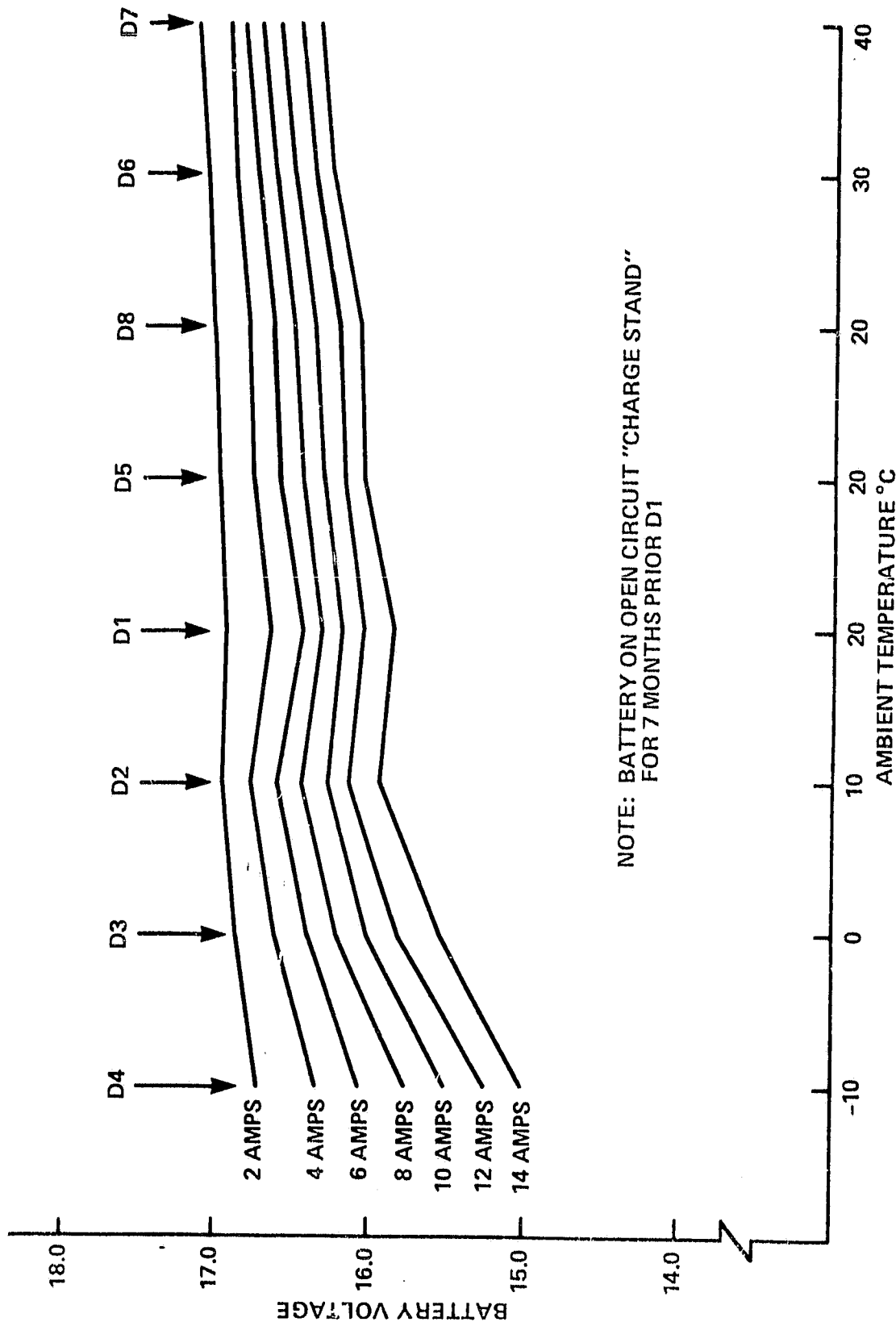


Figure 17. Plateau Voltage Vs Temperature During Sequential Pulsing.

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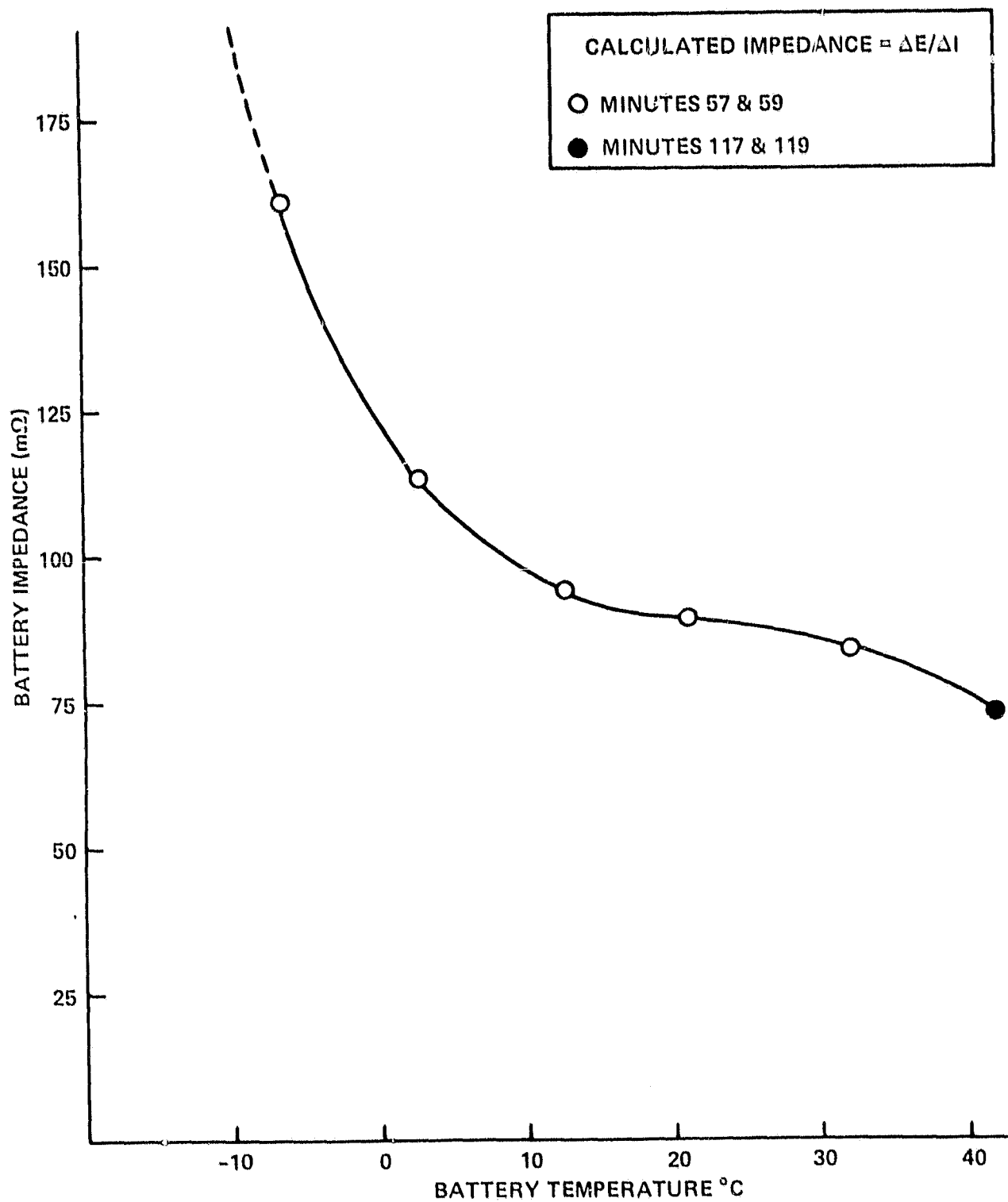


Figure 18. Battery Impedance Vs Temperature.

REFERENCES

1. "Space Shuttle Activation And Recharging Procedures For The Shuttle EMU & MMU Battery," Document JSC 11617 (Rev. A) February 11, 1982
2. "Battery Manufacturing Control Document 04236," Martin Marietta Corporation